DEPARTMENT OF COMMERCE

TECHNOLOGIC PAPERS
OF THE
BUREAU OF STANDARDS

S. W. STRATTON, DIRECTOR

No. 44

INVESTIGATION OF THE DURABILITY OF CEMENT DRAIN TILE IN ALKALI SOILS

(CONTAINING RESULTS OF FIRST YEAR'S TESTS)

By

R. J. WIG, Engineer Physicist
and
G. M. WILLIAMS, Assistant Engineer Physicist
Bureau of Standards

IN COOPERATION WITH

S. H. McCRORY, Chief of Drainage Investigations
Department of Agriculture

E. C. BEBB, Engineer, U. S. Reclamation Service.

L. R. FERGUSON, Assistant Secretary of The Association of
American Portland Cement Manufacturers

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By R. J. Wig and G. M. Williams,

In cooperation with S. H. McCrory, E. C. Bebb, and L. R. Ferguson

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I. INTRODUCTION

The disintegration of concrete when exposed to strongly alkaline soils and waters in arid regions of the western part of the United States has been a subject of discussion by engineers and users of cement for the past 10 or 15 years. There are many concrete

structures in these districts which do not appear to be affected by the salts, but there are some which were apparently made of good materials and were well fabricated which show indications of being attacked.

There are many engineers who believe that well-fabricated concrete will not disintegrate when exposed to these alkali salts and that many cases of failure which have been reported have not been caused primarily by the alkali but resulted from the use of poor aggregate, improper methods of fabrication, or other causes which resulted in a poor quality of concrete.

A laboratory investigation was started in 1908 by the technologic branch of the United States Geological Survey to determine the effect of alkali waters on cements and concretes. In 1910 this work was transferred, by act of Congress, with all structural materials investigations, to the Bureau of Standards. The investigations were continued and the results were published in 1912.[1] Briefly, these investigations showed that practically all cements are attacked by alkali waters upon exposure in the laboratory, and complete disintegration can be obtained under certain conditions. Similar investigations have been made by other laboratories with similar results.[2]

Disintegration in the laboratory can apparently be obtained in two ways. If the cement specimen is somewhat porous and it is constantly supplied with a salt solution which is permitted to crystallize in the pores, disintegration may result from the mechanical force exerted. If hydrated cement is brought into intimate contact with certain sulphate or chloride solutions, the uncarbonated lime of the cement is subject to comparatively rapid solution, with a resulting decomposition of the cement. Laboratory tests, however, must always be interpreted with caution, as conditions often differ somewhat from service, and it is on this account that a field investigation was undertaken in which cement mortar and concrete mixtures of various qualities could be brought into intimate contact with alkali salts under natural conditions.

The Bureau of Standards has made a field survey of concrete structures exposed to alkali waters in several of the Western

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[1] Technologic Paper No. 12, "Action of the salts in alkali water and sea water on cements."

[2] Montana State Agricultural College, Circular No. 8, 1910; Bulletin No. 81, 1910. Colorado Agricultural Experimental Station, Bulletin No. 132.

States. There is a tendency for the cement user to attribute to alkali all failures occurring in these districts, if any alkali is visible in the surrounding soil. Therefore, such failures as occur in the eastern part of the United States, due to poor materials or improper methods of fabrication, are often excused in the irrigated districts as failures due to alkali.

A description of several of the structures which were examined will serve to illustrate the conditions as they exist.

In Fig. 1 is shown a small concrete structure known as a "turn-out" for irrigation water, which was built about 1907. One portion of this structure is completely disintegrated while another portion is sound. The sound portion is a beam on the lower side extending into the wing walls exposed to the earth at each end and located so that half of it is above the concentrated alkali water and half below. The composition of the salts was found to be as follows:

	Per cent
Water soluble	65.33
Insoluble	31.19
Loss at 110° C.	3.14

Analysis of water soluble portion:

	Per cent
CaO	0.04
MgO	.38
Na_2O	43.60
K_2O	.11
SO_3	53.58
CO_2	2.19
Cl	.77

The following method was used for determining the water soluble portion:

Five grams of the sample were heated to 110° C for 18 hours or until constant weight was obtained. This gave "loss at 110° C." This dried residue was digested with 50 cc of water, filtered and washed until practically free from salts soluble in water. The "insoluble" was dried at 110° C and weighed. Aliquot parts of the solution were taken for determination of soluble salts.

The form marks were still visible on the beam when examined in 1912, and it did not appear to have been affected in the least by the alkali salts. The remainder of the structure is completely disintegrated so that it can be torn apart with the hands and the

pores are filled with salts. This canal has never been used for the purpose of distributing irrigation water, and the structure is exposed to the concentrated seepage water which collects from the higher surrounding land and which flows through the ditch.

The beam was molded and cured in the yard and set into place in the "turnout" several days later, at the time the turnout was cast. No records were available to show the composition or method of molding, but it was stated that probably the same materials and proportions were used in both parts of the structure. The primary cause of failure of the disintegrated portion may not be the alkali salts, although it would appear that alkali might be responsible. The excellent condition of the beam, however, would demonstrate that concrete can be made which will resist, at least for a number of years, the action of concentrated alkali of the character found at this locality.

Fig. 2 shows the lower end of a small concrete gate culvert, which is badly disintegrated. Alkali salts are visible on the surface of the soil surrounding the culvert at the lower end. The water carried through the culvert is fresh irrigation water. The walls of the culvert at the upper end appear sound and normal. An analysis of the disintegrated concrete taken from the walls at the lower end give the following results. Two analyses were made of the sample, (a) of the solid lumps, (b) of the soft or crumbly portion.

	(a)	(b)
	Per cent	Per cent
Insoluble: Sand, etc	79.26	65.80
Soluble:		
SiO_2	3.29	3.60
Fe_2O_3	1.20	.80
Al_2O_3	1.57	2.06
CaO	7.02	13.64
MgO	.60	.55
SO_3	.14	.25
Cl	Trace.	Trace.
CO_2	4.67	8.82
Water, etc., at 500° C	2.18	4.39

The foregoing analyses computed to a "sand and moisture free" basis give:

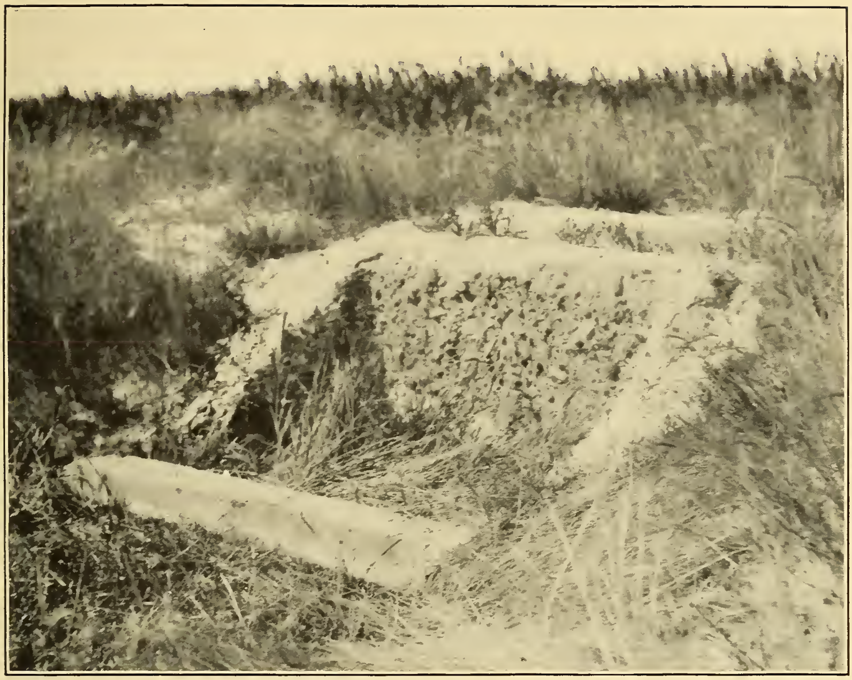

FIG. 1.—*Concrete "turnout" in alkali soil on abandoned irrigation canal, showing the complete disintegration of one portion of the structure, with a premolded beam in the foreground which is perfectly sound. White appearance of disintegrated portion is caused by the alkali salts which fill the pores*

FIG. 2.—*Concrete gate culvert in alkali soil on irrigation canal. Note complete disintegration of concrete in foreground while upper end is perfectly sound. White deposit of alkali is visible on the left above the surface of the water*

	(a)	(b)
Soluble:	Per cent	Per cent
SiO	17.80	12.12
Fe_2O_3	6.49	2.69
Al_2O_3	8.50	6.93
CaO	37.98	45.90
MgO	3.25	1.85
SO_3	.76	.84
CO_2	25.22	29.67

After calculating the amount of MgO and CaO necessary to satisfy the CO_2 and SO_3 there is left in (a) 9.8 per cent CaO and in (b) 10.1 per cent CaO.

These analyses show no abnormality which would account for the disintegration. The sodium and potassium were not determined, but they were evidently not in excess of 1 per cent. The SO_3, Cl, and MgO were also normal. Therefore it would seem that the failure could not have been caused by the alkali, although no other explanation can be offered without a knowledge of the materials used, method employed, and weather conditions at the time of fabrication. This information is not available.

The concrete wing wall of a large culvert shown in Fig. 3 was cited as a case of disintegration due to alkali salts. Upon investigation it was found that there was a bend in the creek at the point where the culvert is located, and during flood the creek carried bowlders 12 to 20 inches in diameter which would be thrown against the wall.

Alkali salts are visible in the pores where the surface is eroded to a considerable depth, but the cement and concrete appears hard and the presence of the alkali would seem to be incidental and contributory rather than the initial cause of disintegration. The composition of the alkali salts taken from the surface was as follows:

Soluble (calculated on 100 per cent basis):	Per cent
CaO	0.91
MgO	.48
Na_2O	41.32
K_2O	Trace.
SO_3	55.98
Cl	.16
CO_2	Trace.

In Fig. 4 is shown a large railroad culvert with a portion of an old concrete structure remaining in the foreground. The concrete remaining from the old structure is completely disintegrated, so that it can be torn apart with the fingers, and alkali salts are found in the pores. The new culvert, which is about eight years old, appears to be sound and normal with the exception of a few spots near the ground line which can be scraped away with a knife. The culvert as a whole does not evidence good workmanship in fabrication.

The surface of the surrounding soil is covered with alkali salts having the following composition:

	Per cent
Water soluble	8.45
Insoluble	78.35
Loss at 110° C	13.98

Analysis of water soluble portion:

	Per cent
CaO	36.16
MgO	.71
Na_2O	5.37
K_2O	.24
SO_3	57.28
Cl	.24

In Fig. 5 is shown a small concrete retaining wall the coping of which is disintegrated and referred to as a failure due to alkali salts. The surface of the soil surrounding this wall, both at the top and along the sides, shows the presence of alkali salts. The wall is sound and hard at all points examined excepting the coping where disintegration is shown. Since structures are found in the East where no alkali salts are present, which appear just as the one shown with the coping sluffed off due to frost action on a very weak section in the concrete that results from the use of watery mixtures, it is quite possible that the disintegration of the coping in this structure is due to that cause. In mixtures in which an excessive amount of water is used the fine material in the aggregate and cement will float to the surface in the forms as they are filled and collect at the top of the form, resulting in a very porous and weak section which is readily attacked by frost.

It is practically impossible to analyze some of the failures which have occurred and state definitely the part played by the alkali salts, as a result of which it was deemed desirable to make field

FIG. 3.—*Concrete wing wall of culvert in alkali soil under irrigation canal. Damage attributed to alkali due to appearance of alkali on eroded surface. Initial erosion probably due to impact of large bowlders brought down by flood water*

FIG. 4.—*Concrete culvert in alkali soil under railway roadbed. Small mass of concrete in foreground remaining from an earlier structure is completely disintegrated. Present structure shows no effect of alkali action although it is considerably cracked from settlement*

FIG. 5.—*Concrete retaining wall in alkali soil. Alkali salts are visible in the surrounding soil. There is no disintegration of concrete in lower section just above water level, where it usually occurs. Disintegrated coping is probably due to use of excess of water in concrete at time of placing*

tests in which concrete of known composition and fabrication would be exposed in some of the worst known alkali districts in the West.

It was decided that this investigation should be started by exposing various cement mixtures in the form of drain tile, because of its economic importance. It will probably become necessary to drain the greater part of all lands under irrigation, and much of this drainage will require the use of tile. The cost of drainage has been estimated as approximately $25 per acre, from which it is seen that many millions of dollars must be spent for this purpose. At the present time there are few known deposits of clay available for the manufacture of satisfactory clay tile in these districts, while materials for the manufacture of cement tile are usually found close at hand, but many engineers are skeptical of the permanency of cement tile, as a number of failures have occurred which have been reported to have been caused by the alkali salts.

This investigation of cement tile should be followed with an exposure of generous sized blocks of concrete of known composition which would simulate mass construction and would extend from below the surface of the ground or water, in order to determine the possibility of disintegration by the mechanical force exerted by the crystallization of the salts absorbed by capillarity into the pores of the concrete above the water or ground surface. It is anticipated that such an investigation will be conducted.

It is desired to thank the United States Reclamation Service and the several project managers and engineers for their assistance and for furnishing the labor necessary in installing the drains at Montrose, Colo.; Garland, Wyo.; Fort Shaw, Mont.; Sunnyside, Wash.; and Yuma, Ariz.; the drainage division of the Department of Agriculture and their field engineers for their assistance and for furnishing the labor necessary in installing the drains at Grand Junction, Colo.; Columbia, Mo.; Crookston, Minn.; Huntington, Utah; and Roswell, N. Mex.; the Iowa State College for providing storage space for a complete set of tile; and P. H. Atwood and the Armstrong Cement Works, Armstrong, Iowa, for their hearty cooperation and interest in the manufacture of the tile. Acknowledgment is also made to the chemical division, A. N. Finn, and

G. J. Hough, of the Bureau of Standards, for the chemical analyses of waters, alkalies, soils, and disintegrated concretes.

II. OUTLINE OF INVESTIGATION

An advisory committee was organized composed of S. H. McCrory, chief of drainage investigations, Department of Agriculture; F. W. Hanna, supervising engineer of the United States Reclamation Service (later succeeded by E. C. Bebb, engineer, Reclamation Service); L. R. Ferguson, assistant secretary of the Association of American Portland Cement Manufacturers; and Rudolph J. Wig, of the Bureau of Standards. This committee held several meetings and finally developed a program which required the manufacture of about 8800 cement drain tile made up of 16 different varieties, as shown in the schedule below.

Schedule of Mixtures and Processes of Manufacture of the Tile

Series	Proportions cement-sand	Consistency	Manufacture	Curing
1	1:2½	Plastic	Handmade	Sprinkling
2	1:2½	Quaking	do	Do.
3	1:2	Plastic	do	Steam
4[a]	1:2	do	do	Do.
5[b]	1:2	do	do	Do.
6[c]	1:2	do	do	Do.
7	1:3	do	Machine-made	Do.
8	1:4	do	do	Do.
9	1:1½	do	do	Sprinkling
10	1:1½	do	do	Steam
11	1:3	do	do	Sprinkling
12	1:4	do	do	Do.
13	1:2½	do	do	Steam
14	1:3	Fluid	Handmade	Sprinkling
15[d]	1:3	do	do	Do.
16[e]	1:4	Plastic	Machine-made	Steam

[a] Dipped in neat cement grout, 20 to 24 hours after molding.
[b] Dipped in hot tar 6 weeks after molding.
[c] 10 % ferrous sulphate, by weight, added to mixed water.
[d] Sand-cement used in place of Portland cement.
[e] From factory stock pile. Northwestern States Portland cement. Age probably 6 months when above series were made.

The tile were made as described later, under contract at a commercial tile plant, and under the supervision of a representative of the Bureau of Standards. Work was commenced in July and

completed in September, 1913, and shipments were made in October, which allowed a curing period of one month for the last tile made. Although it was anticipated that some of the tile of the leaner mixtures which are satisfactory in the humid regions would fail in these alkali soils, the program was arranged to include tile made from the leanest to the richest commercial mixtures.

The tile were installed in operating drains on eight projects in the most concentrated alkali soils available in the West and on projects where there was practically no alkali for comparison. The location of these projects is as follows:

Alkali projects: Garland, Wyo.; Fort Shaw, Mont.; Huntington, Utah; Sunnyside, Wash.; Yuma, Ariz.; Roswell, N. Mex.; Grand Junction, Colo.; Montrose, Colo.

Fresh-water projects: Crookston, Minn.; Columbia, Mo.

One set of tile of each type also was stored in the open exposed to the atmosphere at Ames, Iowa, for reference and test.

The program requires the removal of at least two tile of each type at each project every year for test and inspection. Sufficient tile were made and installed to continue the investigation 10 years or longer if necessary.

To replace the tile which were removed for test during 1914 a supply of 8-inch cement tile were furnished by the Universal Portland Cement Co. A description of the materials and methods used for the manufacture of these tile is included under the heading "Manufacture of drain tile." A group of each of these series, numbered 17 and 18, will be removed in 1915 when the second year's tests will be made.

Tile removed for test during 1915 will be replaced by cement tile furnished by the Utah Concrete Pipe Co., Salt Lake City, Utah.

III. MANUFACTURE OF DRAINTILE

1. FACTORY AND EQUIPMENT

The cement test pieces used in this investigation were made at the tile plant of the Armstrong Cement Works, Armstrong, Iowa. This factory has for a number of years been producing large quantities of cement tile, varying in size from 4 to 30 inches, for use in northern Iowa.

The factory building consists of a concrete block and frame structure, which houses the mixers and tile-making machines, with a large low-roofed concrete block addition to one side, which is divided into curing chambers. A railroad switch used for the delivery of materials and shipment of the finished product parallels the building on the opposite side.

Sand is received in dump-bottom coal cars and dropped into a pit, from which it is drawn by a chain drag to the foot of a bucket elevator. After being elevated the sand is dropped into either of two storage bins, or is carried overhead on a belt directly to a sand-storage box, placed above the hopper of a batch mixer. In making commercial tile this hopper is filled with sand to a fixed height, depending upon the proportions desired, and the cement is added. The gate is then opened and the material passes into the batch mixer, which consists of a cylindrical steel drum mounted on rollers. The interior of the mixer contains scoops or buckets, which carry the material up and drop it during rotation. This mixer is very satisfactory in use, mixing the sand and cement uniformly and quickly, but the time required varies considerably, due to the varying amounts of moisture in the sand. A very damp sand generally requires two or three times as many revolutions of the mixer as does a dry sand.

After the cement and sand are thoroughly mixed dry the mass is dropped into another hopper just above a continuous mixer or pug mill. (See Fig. 6.) As the dry material is fed into the upper end of the trough of the pug mill, water is sprayed in through a perforated pipe, the amount being regulated by the man at the mixer. To obtain a uniform mixture an experienced man is required, as the rate of feed of the material and the amount of moisture in the sand vary constantly.

This factory is equipped with several tile machines, the Schenck being used in making all the experimental machine-made tile. This machine is of the revolving packer type, the tile being formed between the stationary metal jacket and the packer, which is drawn upward and out of the tile as it revolves.

The car system is in use for handling the smaller sizes of tile after molding. The equipment consists of a suitable number of

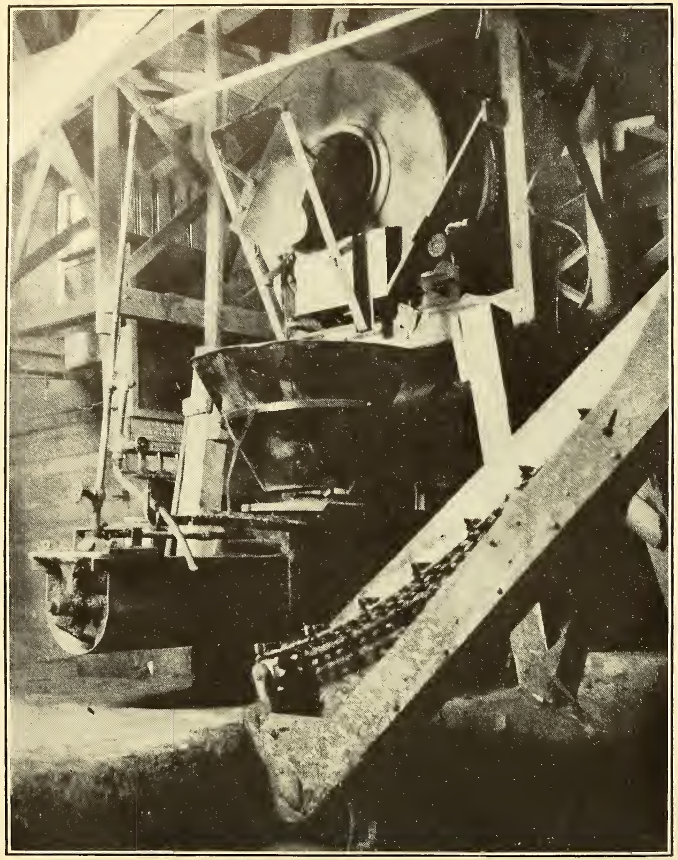

Fig. 6.—*Combination batch mixer and pug mill. Materials are thoroughly mixed dry in cylindrical steel drum, then dropped into hopper above pug mill into which the dry mixture flows in a small continuous stream. Water is added through a perforated pipe as the materials are forced through the horizontal trough by the rotating blades*

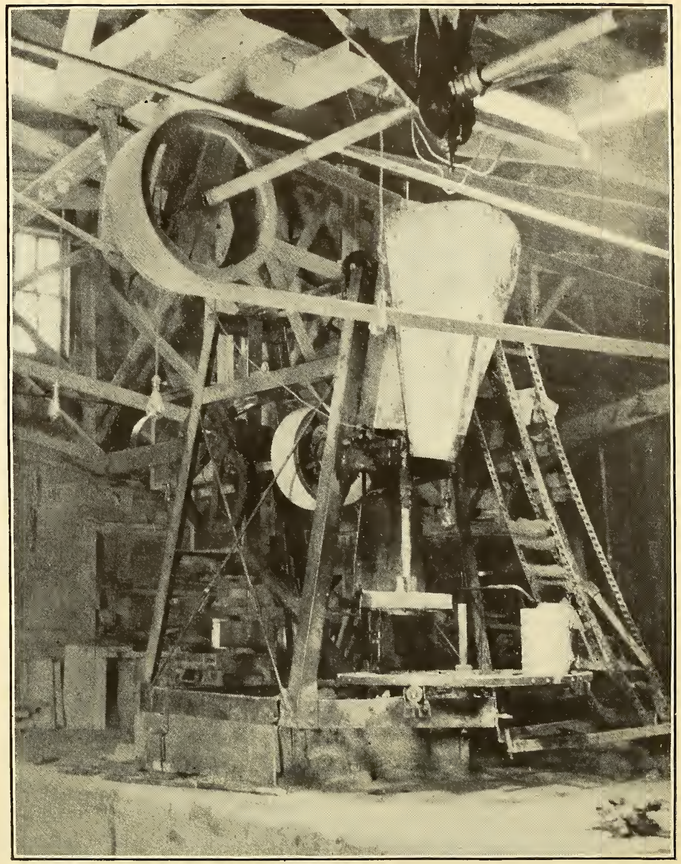

Fig. 7.—*Schenck cement tile machine. When the packer head on the vertical rotating shaft is in its lowest position cement mortar is automatically dumped into the mold by a bucket elevator and the material is packed against the wall of the mold by the rotating packer head as it is withdrawn vertically*

three-deck cars equipped with springs and roller bearings, transfer trucks, and trackage into the curing chambers and out to the various points in the storage yard.

Steam curing of concrete products is used exclusively for curing the regular output of this factory, but all rooms are equipped with water pipes for sprinkling the product, which was the method desired for several of the series of our experimental tile. Cars containing small tile are pushed into low-roofed block-walled rooms, about 90 feet long, holding 11 cars, with enough clearance on one side to allow a man to pass along the cars and sprinkle the tile. Large tile, wheeled on carts, are cured in two large rooms having concrete floors. Exhaust steam from the engine of an electric lighting plant, owned by the same company, is piped to the various rooms and utilized for curing. Steam was available 16 hours per day.

2. MATERIALS

The cement used in this work was Hawkeye brand Portland cement, supplied under contract by the Iowa Portland Cement Co., Des Moines, Iowa. Approximately 240 barrels of Portland cement were required. For the manufacture of series 15, a sand cement was supplied by the United States Reclamation Service, from the sand-cement mill in operation at Arrowrock, Idaho. The results of chemical and physical tests of the cements are given in Table 1.

The sand used was shipped in from Mason City, Iowa, being the material regularly used in the factory.

Analysis and tests of sand are shown in Table 2. The water was pumped from a well at the factory. Power was furnished to the entire equipment by a 20-horsepower electric motor, receiving current from the electric lighting plant.

3. MACHINE-MADE TILE

These tile made on the Schenck cement tile machine (Fig. 7) are 12¼ inches in length, three-fourths inch thick, with an inside diameter of 8 inches.

TABLE 1

Results of Tests of Cement Used in Manufacture of Cement Drain Tile

HAWKEYE PORTLAND CEMENT

Sample	Specific gravity	Fineness		Time setting		Soundness		
		100-mesh	200-mesh	Initial	Final	A	W	S
		Per cent	Per cent					
1	3.16	94.0	77.8	5–45	10–15	O. K.	O. K.	O. K.
2	3.15	93.8	76.6	5–55	9–45	O. K.	O. K.	O. K.
3	3.16	94.0	77.0	5–50	9–40	O. K.	O. K.	O. K.
4	3.16	93.6	77.4	5–55	9–35	O. K.	O. K.	O. K.
5	3.15	94.4	78.8	5–50	9–00	O. K.	O. K.	O. K.

Chemical Analysis

	Per cent
SiO_2	22.94
Fe_2O_3	4.20
Al_2O_3	4.90
CaO	62.08
MgO	1.27
SO_3	1.64
Loss	1.57
Insoluble residue	0.29

Tensile Strength (pounds per square inch)

[Average of three briquettes]

Sample	7-day mortar	7-day neat	28-day mortar	28-day neat
1	205	543	290	725
2	200	562	279	711
3	224	517	325	718
4	220	533	308	722
5	257	584	321	647

SILICA CEMENT

Specific gravity	Fineness		Time of setting		Soundness
	100-mesh	200-mesh	Initial	Final	
	Per cent	Per cent			
2.89	99.4	90.4	2–40	6–45	O. K.

Chemical Analysis

	Per cent
Soluble in HCl:	
SiO_2	13.00
Fe_2O_3	3.46
Al_2O_3	1.40
CaO	37.78
MgO	1.65
SO_3	0.87
Insoluble in HCl:	
SiO_2	31.52
Al_2O_3	6.54
MgO	0.59
Ignition loss	2.41

Possible Composition

Cement	61.3
Clay and silicious material	38.7

Tensile Strength (pounds per square inch)

[Average of three briquettes]

7-day mortar	7-day neat	28-day mortar	28-day neat
180	457	295	537

TABLE 2

Results of Tests of Sand Used in the Manufacture of Cement Drain Tile

[Specific gravity of sand=2.655]

	1 : 3 mortar briquettes	
	7-day	28-day
Washed sand	282	388
Sand as received	237	348
Sieved to pass No. 20; held on No. 30	191	283
Standard Ottawa sand	205	290

Granular Analysis of Sand

[Uniformity coefficient=3.30; per cent of silt=3.9]

Sand passing sieve No.—	Per cent
200	0.89
100	1.56
80	5.31
50	18.04
40	27.81
30	46.35
20	67.26
10	84.61
Retained on No. 10	15.38

83474°—15——2

TESTS OF MATERIALS USED IN MANUFACTURING REPLACEMENT TILE, 1914

TABLE 3

Results of Tests of Universal Portland Cement

Sample	Specific gravity	Fineness		Time of setting		Soundness		
		100-mesh	200-mesh	Initial	Final	A	W	S
		Per cent	Per cent					
1	3.09	97.2	78.9	1–20	5–15	O. K.	O. K.	O. K.

Chemical Analysis

	Per cent
SiO_2	19.84
Fe_2O_3	1.30
Al_2O_3	7.30
CaO	62.90
MgO	2.30
SO_3	1.42
Loss	2.83
Insoluble	.32

Tensile Strength

[Average of three briquettes]

7-day mortar	7-day neat	28-day mortar	28-day neat
214	527	281	664

TABLE 4

Results of Tests of Sand

[Average of three briquettes (pounds per square inch)]

	7 days	28 days
Tensile strength:		
Proportion 1–3 by weight	310	434
Compressive strength:		
Proportion 1–1½, two-inch cubes	3,545	5,863
Proportion 1–2, two-inch cubes	2,732	5,440
Proportion 1–2 (2 parts sand, 3 parts gravel), two-inch cubes	3,725	5,675

Granular Analyses

Sand passing sieve No.—	Per cent
100	1.99
50	14.39
40	21.21
30	33.31
20	48.01
14	55.78
10	66.73
8	76.63
Retained on No. 8	23.37

Gravel: All material passed the one-half-inch screen and was retained on the No. 8 sieve.

Sand was brought to the proportioning hopper, as stated above, except that it was first dropped into a large box placed on a platform scale on the upper mixing platform. All proportions were determined by weight, every batch of sand used being weighed and then dropped in the hopper above the batch mixer, where the cement was added. The material was then dropped into the batch mixer, which revolved continuously, the slide of the hopper again closed, and another batch of the material prepared. Usually one batch would be passing through the pug mill, a second being mixed in the batch mixer, and a third being prepared in the proportioning hopper so that the pug mill could be operated continually to its full capacity.

Usually one man can prepare the batches and keep the pug-mill hopper filled, but on account of the extra labor caused by the weighing of the sand two men were used while the "machine" tile were being made. Two men were also required to regulate the water supply and shovel the mixed material into the elevator boot of the Schenck machine. One man is required to operate the machine, two men are used in stripping jackets from the tile (which were placed on the car decks only a step or two away from the machine), one man is required in the sand pit, and another to push out loaded cars and bring back the empty cars, so that a total of nine men were required to operate the machine at its highest efficiency.

The quantity of water required for various batches of each series was measured by passing the water supply through a barrel whose contents were known for each inch in depth. The amount was then determined by measurement.

Due to the variation in the amount of moisture in the sand and to the use of a continuous mixer in which the water was added, it was impossible to add a predetermined or fixed quantity of water to every batch of dry material. In every case an attempt was made to make the mixture as wet as possible and still allow the immediate removal of the jacket. Too small or too great an amount of water in case of the lean mixtures will cause the tile to crumble or crack in removing the jacket or collapse during the shifting of the car. A rich mixture containing a small excess of

water will usually hang together, due to the "stickiness" of the cement, but it is likely to be distorted unless the jacket is stripped with unusual care. Too little or too much water will usually cause immediate trouble at the machine, greatly cutting down the output. The proper amount is indicated very plainly by the web like markings of neat cement on the outer surface of the tile.

The cars in use (Fig. 8) hold ninety-seven 8-inch tile, but usually the number of good tile was less, due to the sorting out of the culls, which were caused either by the failure of the machine to work properly or by carelessness on the part of the strippers in removing the jackets. This loss can be avoided and the green material remolded if the damaged tile are removed at once.

After placing in the curing room the tile were sprinkled twice, if to be steam cured—once in the evening of the day made and again during the following morning, steam having been turned on during the night. The steam-cured tile were exposed to steam for a total period of 96 hours, 16 hours per day, after which they were piled in the storage yard. The water-cured tile were sprinkled twice daily for a period of 12 days and then removed and piled in the storage yard.

The temperature of the moist air in the curing rooms varied from 110° to 120° F. during the period in which the steam was on.

The water-cured tile were allowed to harden under much more favorable conditions than are usually understood by the term "water curing." Too often "water cured" means that tile are stored in an open shed, or, at best, in a large room containing many doors and windows, and sprinkled one or more times a day. In the case of these experimental water-cured tile the cars were run into the long, narrow curing rooms which are continually damp, with wet floors, and perfectly protected from the sun and air currents. The amount of evaporation under these conditions is small compared to that in a large room or shed.

4. HANDMADE TILE

The handmade tile were made of two types, the semiwet series and the wet series. These tile have an inside diameter of 8 inches, with smooth walls 1½ inches thick and 12¼ inches long, made in sheet-metal molds provided especially for this work.

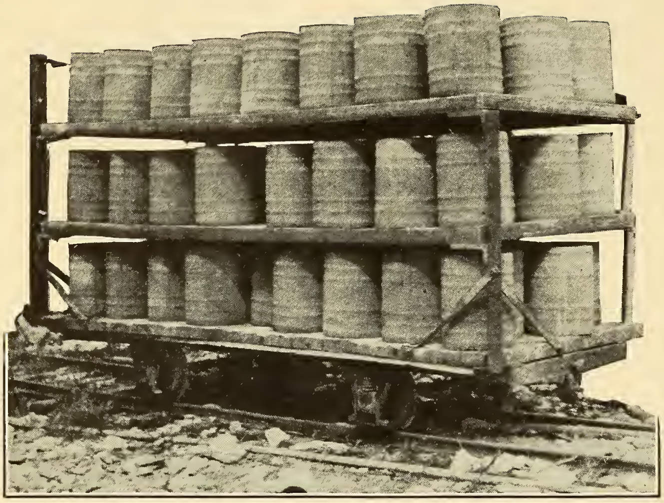

Fig. 8.—*Machine-molded cement tile, showing method of handling drain tile in a modern tile factory with 3-decked cars. The tile shown are of series 10, which have just been drawn from the steam curing chamber*

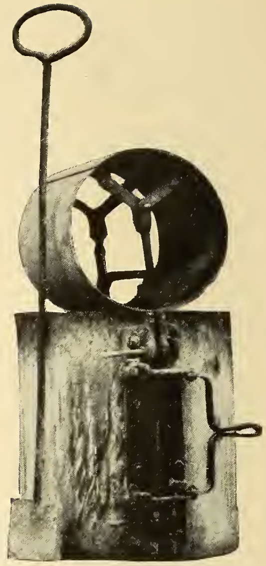

Fig. 9.—*Mold for 8-inch handmade cement tile. Sheet-metal mold consisting of outer jacket and collapsible inner core. Tamping iron used in molding tile is also shown*

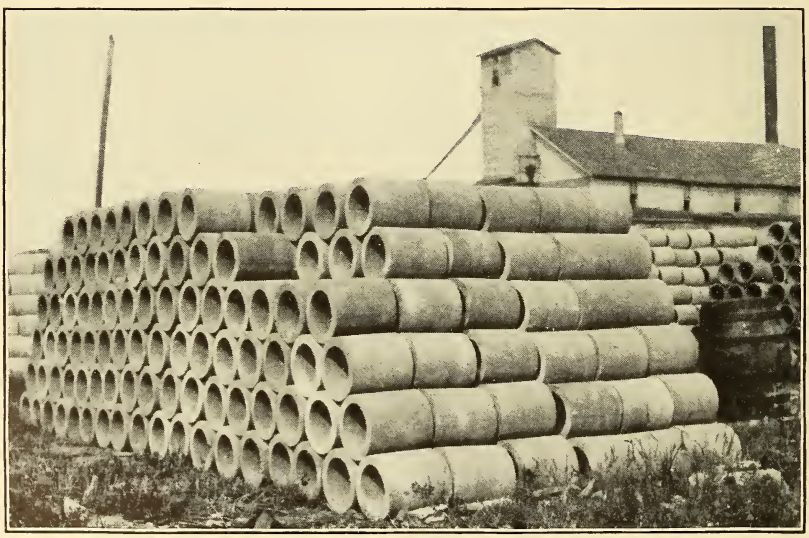

Fig. 10.—*Handmade cement tile stored in yard at factory after completion of curing period. The tile in foreground are a complete set of series 1 ready for shipment*

(See Fig. 9.) The great difficulty in the use of such molds is in keeping the core centered so that the walls of the resulting tile will be of uniform thickness. Several methods were tried to secure the proper results, and the one found simplest and most satisfactory consisted of a wooden base with two concentric circles of small headless nails projecting up about three-eighth inch above the boards. These nails were placed on the inner and outer circumference of two circles having diameters of 8 and 11 inches, respectively. This arrangement provided for the centering of the lower end, but it required careful use of the tamping iron to obtain a uniform wall thickness at the top. Molds made of heavier metal would be more satisfactory in this respect, but the cost would have been excessive for this experimental series.

The process of proportioning and mixing of the materials up to the addition of the mixing water was in every way similar to that of the machine-made tile.

Series 1, 3, 4, 5, and 6 were of the plastic consistency, containing as much water as would allow the immediate removal of core and jacket. However, it was found that the material for these handmade tile had to be slightly drier than that which could be used on the machine, probably due to less pressure being exerted in hand tamping, making the tile less dense.

The semiwet handmade tile (Fig. 10) were molded on the concrete floor of one of the large curing rooms and were sprinkled in the evening of the day molded. The following morning they were again sprinkled and then placed on cars and shifted into the low-roofed curing rooms, where the steam or water treatment was continued for the proper length of time. In the manufacture of series 6, 10 per cent of ferrous sulphate, by weight, was added to a known weight of water in the measuring barrel, and this solution, kept well stirred, was used in mixing.

The tile of series 14 and 15 were made of a much wetter consistency than those of the other series. These tile contained sufficient water so that they could be easily poured into the mold from a small bucket. The tamping iron was used along the walls of the mold to aid in removing air bubbles from the surfaces. The tile of series 2 were of an intermediate consistency, and required considerable tamping in small layers in order to prevent the

formation of "rings" or roughened surfaces. The tile of these series were piled in one of the long curing chambers and sprinkled twice daily for at least 10 days.

5. CONSISTENCY OF MIXTURES USED

The following consistencies were used in the manufacture of the tile:

PLASTIC.—As much water was added to the dry-mortar mixture as would permit the immediate removal of the jacket from the tile. This condition is indicated by the weblike marks of neat cement and water on the outer surface of the wall. This consistency was used for making the tile of series 1, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, and 16.

QUAKING.—Moisture could easily be brought to the surface by tamping. The material would settle about three-eighths inch in the mold during the first two hours after molding. This consistency was used for making the tile of series 2.

FLUID.—This material was of such a consistency that it could be easily poured into the mold. It would settle one-half to three-fourths inch in the molds during the first four hours after molding. This consistency was used for making the tile of series 14 and 15.

6. DETAILED DESCRIPTION OF EACH TYPE OF TILE

Following is a description of the tile of each of the various series, together with any notes on manufacture peculiar to each:

SERIES 1.—Proportions, by weight, one part Portland cement to two and one-half parts sand, plastic consistency, hand tamped, and cured by sprinkling. An average of 7.7 tile was obtained from each bag of cement.

SERIES 2.—Proportions, by weight, one part Portland cement to two and one-half parts sand, quaking consistency, hand tamped, cured by sprinkling with water. An average of 7.2 tile was obtained from each bag of cement.

SERIES 3.—Proportions, by weight, one part Portland cement to two parts sand, plastic consistency, hand tamped, stored in air for first 24 hours, then a total of 102 hours in steam. An average of 7.6 tile was obtained from each bag of cement.

SERIES 4.—Proportions same as series 3. Cured 24 hours in air, then dipped in neat cement grout, loaded on cars and exposed to steam for a period of 102 hours. An average of 6.9 tile was obtained from each bag of cement allowing for cement required for grouting.

SERIES 5.—Proportions and method of curing same as series 3. Tile then stored in yard and dipped in boiling tar when six weeks old. An average of 7.2 tile was obtained from each bag of cement.

SERIES 6.—Proportions and method of curing same as series 3, except that 10 per cent of ferrous sulphate, by weight, was added to mixing water. An average of 7 tile was obtained per bag of cement.

SERIES 7.—Proportions, by weight, one part Portland cement to three parts sand, plastic consistency, machine-made, steam cured. These tile were loaded on cars and placed in the curing chambers immediately after making. Steam was turned on within a few hours and continued for a total period of 96 hours. An average of 14 tile was obtained per bag of cement.

SERIES 8.—Proportions, by weight, one part Portland cement to four parts sand, plastic consistency, machine-made, cured in steam for a total period of 96 hours. An average of 18.8 tile was obtained per bag of cement.

SERIES 9.—Proportions, by weight, one part Portland cement to one and one-half parts sand, plastic consistency, machine-made, cured by sprinkling with water for a period of 12 days. An average of 8.7 tile was obtained per bag of cement.

SERIES 10.—Proportions, by weight, one part Portland cement to one and one-half parts sand, plastic consistency, machine-made, cured in steam for a period of 96 hours. This series differs from series 9 only in the method of curing. An average of 8.7 tile was obtained per bag of cement.

SERIES 11.—Proportions, by weight, one part Portland cement to three parts sand, plastic consistency, machine-made, cured by sprinkling for a period of 12 days. This series differs from series 7 only in the method of curing. An average of 13.7 tile was obtained per bag of cement.

SERIES 12.—Proportions, by weight, one part Portland cement to four parts sand, plastic consistency, machine-made, cured by sprinkling for a period of 12 days. This series differs from series 8 only in the method of curing. An average of 18.4 tile was obtained per bag of cement.

SERIES 13.—Proportions, by weight, one part Portland cement to two and one-half parts sand, plastic consistency, machine-made, cured in steam for a total period of 96 hours. An average of 12 tile was obtained per bag of cement.

SERIES 14.—Proportions, by weight, one part Portland cement to three parts sand, fluid consistency, hand tamped, cured by sprinkling for a period of at least 12 days. Greater part of settling of material in molds took place during the first hour, after which the molds were refilled with some of the same material tamped and troweled. An average of 8 tile was obtained per bag of cement.

SERIES 15.—Proportions, by weight, one part sand-cement to three parts sand, fluid consistency, hand tamped, cured by sprinkling with water for a period of at least 10 days. Molds refilled with same material, tamped and troweled, after settling had taken place. These tile required very careful handling when the molds were removed on the day after molding to avoid breakage. An average of 7.4 tile was obtained per bag of cement.

SERIES 16.—Proportions, by weight, one part Northwestern States Portland cement to four parts sand, plastic consistency, machine-made, cured in steam. This series, which was taken from the stock pile of the Armstrong Cement Works, represents the regular commercial output of this factory. No especial care was used in selection, except to throw aside tile which were cracked or had jammed ends. The exact age of this series is uncertain but the tile are probably at least six months older than those of the preceding series.

The machine-made tile varied in weight from 23 to 25.25 pounds, averaging 24 pounds; the semiwet hand-tamped tile varied in weight from 42.25 to 45 pounds, averaging about 43.2 pounds; tile in series 15, sand-cement, averaged about 41.5 pounds.

The difference in appearance of the surfaces of the different series is shown in Figs. 11 to 14. The appearance varies with the

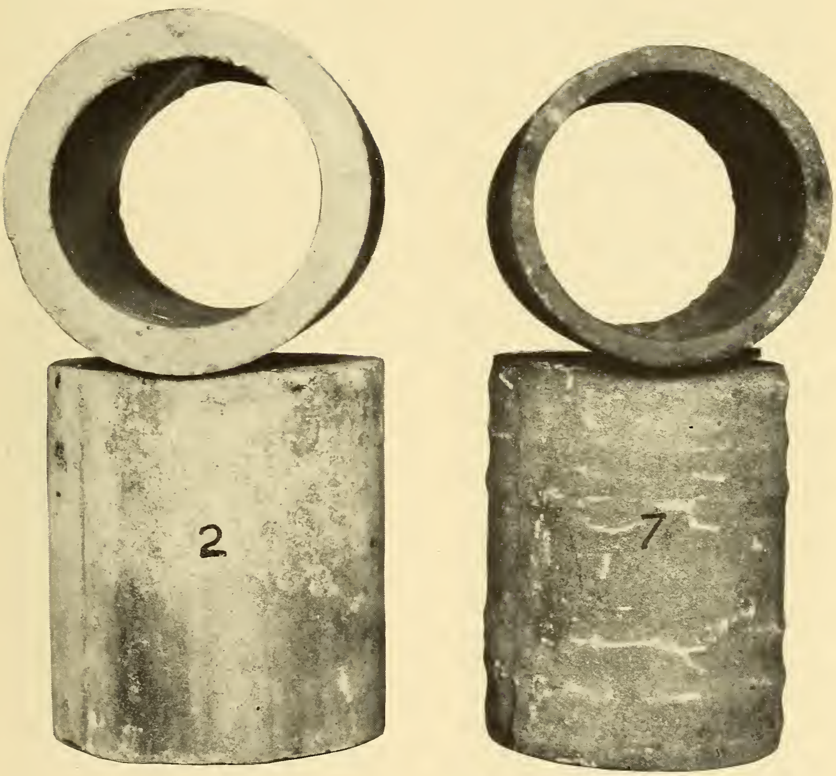

FIG. 11.—*Handmade tile of series 2, made of a quaking consistency mortar, and machine-made tile of series 7, made of plastic consistency mortar, showing the texture of the surface and relative size of the two types*

Fig. 12.—*Appearance of machine-made tile of rich and lean mixtures. Tile marked 10 is composed of one part cement to one and one-half parts sand; tile 7, one part cement to three parts sand; and tile 12 and 16 are one part cement to four parts of sand, all made by the same process excepting 12, which was cured by sprinkling instead of exposing in steam*

FIG. 13.—*Appearance of handmade tile of different consistencies. Tile marked 1 was made of plastic consistency; 2 of quaking consistency, and 14 of fluid consistency. Tile 1 and 2 are composed of one part cement to two and one-half parts of sand; tile 14 of one part cement to three parts sand*

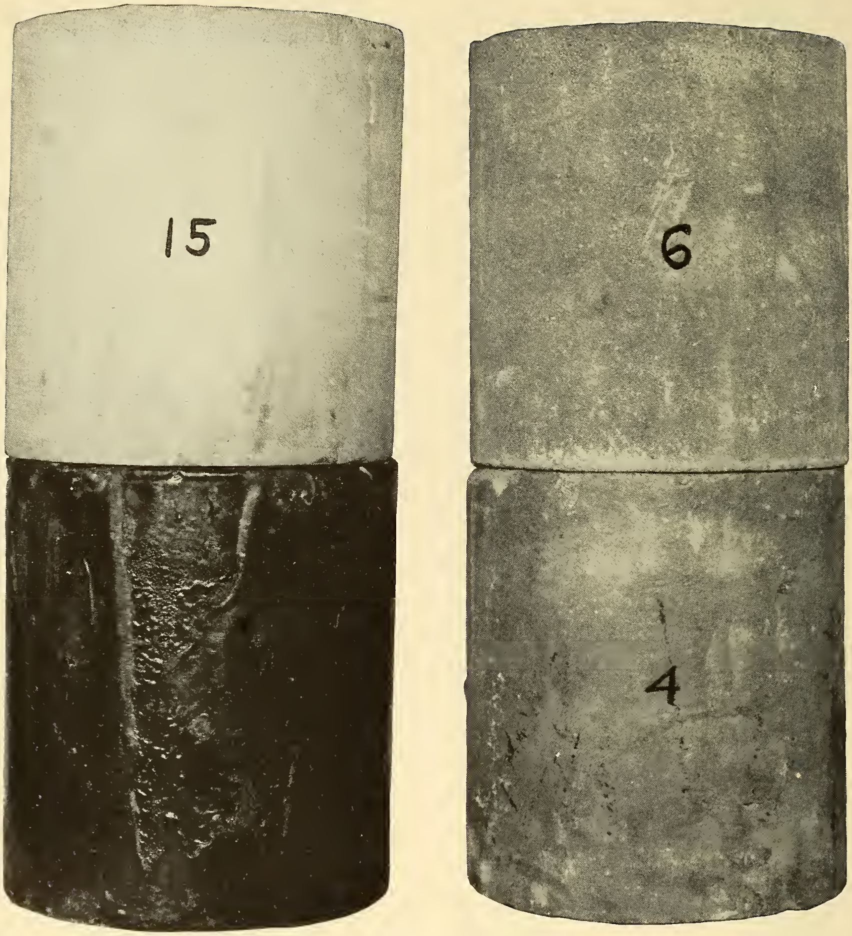

FIG. 14.—*Appearance of special and treated tile. Tile of series 4, 5, and 6 were all made by the same process. No. 4 was dipped in cement grout, 5 in hot tar, and 6 was treated by adding ferrous sulphate to the water used in mixing. Tile of series 15 were made of one part sand-cement to three parts of sand mixed to a fluid consistency*

richness of the mixture as well as the method of molding. Of the machine-made series, 9 and 10, the richest, are lightest in color with more of a glazed appearance while the leaner mixtures are darker in color and have more of a sandy, roughened appearance. In the handmade series, No. 15 is nearly white with a "chalky" appearance, due to the use of sand-cement. In series 2, 14, and 15 the handmade tile of quaking and fluid consistency have rather smooth surfaces with numerous small and shallow indentations due to air pockets on the walls of the molds. The plastic mixtures of the handmade tile series 1, 3, and 6 have rough surfaces as a rule and in a few cases irregular and insufficient tamping was indicated by the appearance of circumferential rings of porous appearing concrete.

Throughout this work no departure from the regular processes in use at this plant were made except that the proportions were varied and all the materials were weighed to insure uniformity. No specially chosen aggregates were used, the sand being that used in the factory for the manufacture of all kinds of cement products and the cement being purchased under bids with the requirement that it was to pass the United States Government specification for Portland cement. Although some of the mixtures contain more cement than those in ordinary commercial use, and it is not practicable to make a handmade tile which can compete in price with the usual machine-made tile, any well equipped and managed factory using good materials should be able to turn out a product which is as good in every respect as has been provided for this investigation.

7. REPLACEMENT TILE

The tile supplied to replace those tested during the year 1914 were supplied by the Universal Portland Cement Co., and were designated by the series numbers 17 and 18. These tile were 12 inches in length, of 8 inches inside diameter, with a wall thickness of 0.8 inch.

All concrete was machine mixed, sufficient water being added that the mixture would just hold its shape when piled with a shovel and would not splash out of the molds when agitated. The

sheet-metal molds were filled with an excess of material in a funnel attached to the top of the form. The mold was then placed upon the jigging-machine platform and the machine operated for a period of 30 seconds. The drop of this platform was $\frac{13}{32}$ inch while the platform made 120 complete trips through this space per minute.

Two sizes of aggregate were used, a sand of good quality passing the one-fourth inch screen and a gravel passing a one-half inch round opening and retained on a No. 8 sieve. The sample of cement used in the manufacture of these series was lost in transit and the results shown in Table 3 were obtained on a sample of the same brand of cement which was submitted six months later. The proportions used were as follows:

SERIES 17.—One sack of cement to 1½ cubic feet of sand.

SERIES 18.—One sack of cement to 2 cubic feet of a mixture of fine and coarse aggregates, which were mixed in the proportion of two parts sand to three parts one-fourth inch to one-half inch gravel.

The tile were removed from the molds on the following day and then piled in one corner of the laboratory and covered with sand which was kept constantly wet.

The surface of these tile had much the same appearance of that of the tile of series 2, 14, and 15, since they were made of a quaking consistency.

After these tile had cured for a period of at least one month they were crated in wooden crates holding six tile each and shipped to the various projects and later installed in the place of those removed for test.

IV. INSTALLATION OF DRAIN TILE

1. SHIPMENT

Shipments of the tile from the factory at Armstrong, Iowa, were made early in October, 1913. A carload (about 780 tile) was shipped to each project, each shipment consisting of 50 tile of each series, with the exception of series 5 and 15, of which 45 and 36, respectively, were sent. The tile were piled with their walls parallel to the car sides beginning at either end, and tiered

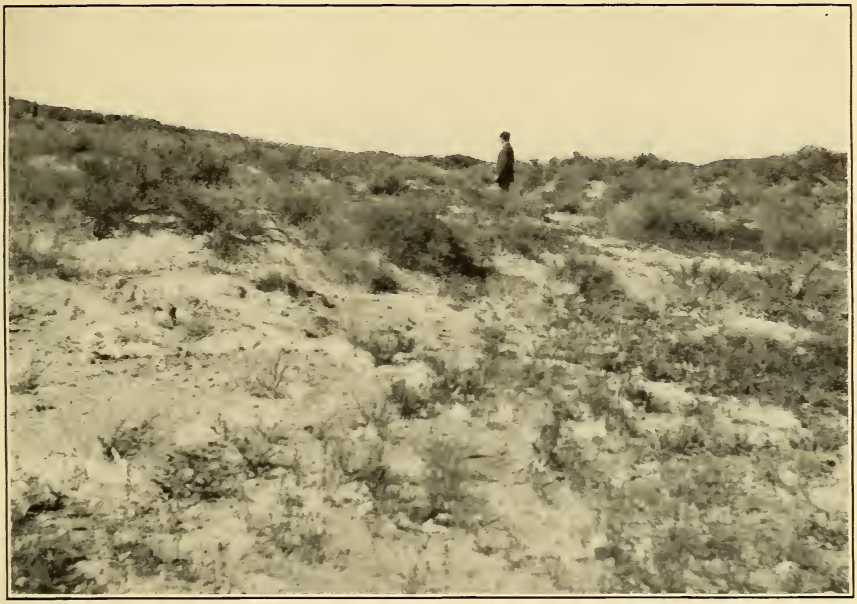

FIG. 20.—*Site of experimental drain, lower end, at Garland, Wyo., showing heavy incrustations of alkali on surface and character of the vegetation. This site is usually swampy from seepage water, and the alkali concentration may be considered as bad as any to be found in the State*

FIG. 21.—*View of opened ditch at silt basin experimental drain at Garland, Wyo., showing the gravel soil and seepage water in the trench above the grade of the drain; also the wooden cradles shown on the left upon which the tile were placed*

three and four high, depending upon the length of the car. This arrangement was continued up to within 3 feet of the doorway where the number of layers was reduced to two and then one. The doorway space was occupied by several rows one tile high, placed so as to block the lower layer in the two ends. To reduce the breakage a thin layer of straw was spread over the floor and between the layers. The cars arrived at their destination showing little evidence of the tile having been thrown out of place while in transit, although no framing whatever was used to keep them in position. Breakage was due almost entirely to wedging of tile in the lower layers. This wedging action was probably aided by the "giving" of the car sides while in motion. In some cases no record of breakage was kept at the time of unloading, so that the following figures include the loss in unloading and hauling of the tile at destination.

The length of wagon haul and the total breakage is recorded in the following table:

Location	Wagon haul	Loss	Location	Wagon haul	Loss
Garland................miles..	3½	3	Grand Junction........miles..	2	9
Fort Shaw.................do..	1	3	Montrose..................do..	12	22
Huntington................do..	24	18	Columbia..................do..	1½	22
Sunnyside.................do..	1	8	Crookston..............yards..	800	6
Yuma......................do..	2	18	Ames.....................feet..	400	3
Roswell...................do..	5	4			

A total of 116 tile were broken out of over 8500 shipped, an average railway haul of about 1300 miles, and a wagon haul of over 4.5 miles. The average loss by breakage is 1.3 per cent.

2. COMPOSITION OF ALKALI AND SOIL AT DRAIN SITES

The character of alkali found at the site of the drains is given in Table 5. The alkali samples were obtained by scraping the salts from the surface of the ground at all points excepting at Crookston, Minn., and Columbia, Mo., where soil samples only were taken. The composition and concentration of alkali in the soil at the level of the drain is given in Table 6. Analyses of the waters flowing in the various drains are given in Table 7.

The analyses of the alkalies, soils, and waters are given in percentages of the soluble or dissolved material present. Figs. 15, 16, and 17 show graphically the results calculated on the basis of percentage reacting values as discussed by Stabler in Water Supply Paper 274, and Palmer in Bulletin 479 of the United States Geological Survey.

The reacting value is the chemical reacting power of the radicle in terms of the hydrogen equivalent and may be calculated in a number of ways. The reacting values included in this paper were obtained by multiplying the weight of the radicle in milligrams by the reaction coefficient. The reaction coefficient was obtained by dividing the valency of the radicle by its combining weight. Expressed as an equation

$$\text{Reacting value} = \frac{\text{Weight of ion or radicle in milligrams} \times \text{valency}}{\text{combining weight}}$$

For example:

Reacting value

$$Na = \frac{\text{Weight in mg} \times 1}{23.1} = \frac{\text{Weight in mg}}{23.1} = .0433 \text{ weight in mg.}$$

$$SO_4 = \frac{\text{Weight in mg} \times 2}{96} = \frac{\text{Weight in mg}}{48} = .0208 \text{ weight in mg.}$$

The percentage reacting value of each radicle was then determined.

TABLE 5

Analyses of Alkalies from Surface of Ground at Site of Drain November, 1913

[Analyses of mineral matter in per cents]

Location	Na_2O	K_2O	CaO	MgO	SO_3	Cl
Garland, Wyo	41.54	0.56	0.76	0.60	56.36	0.60
Fort Shaw, Mont	34.45	.26	3.22	1.75	59.20	1.07
Sunnyside, Wash. (Station No. 1)	30.20	.22	.84	9.28	50.20	9.27
Roswell, N. M. (Station No. 15+15)	13.60	2.43	21.92	7.68	33.65	20.60
Montrose, Colo	11.27	None.	2.58	39.80	46.40	.03
Grand Junction, Colo	35.66	None.	.91	10.22	37.40	15.82
Huntington, Utah	36.88	.74	3.30	4.10	55.00	.12
Yuma, Ariz	26.68	.32	8.23	12.67	10.00	42.10

TABLE 6

Analyses of Soils at Level of Tile Drains November, 1913

[Analyses of mineral matter in per cents]

Location	Per cent soluble solids	Na_2O	K_2O	CaO	MgO	SO_3	Cl	CO_2	SiO_2
Garland, Wyo	0.85	11.41	Trace.	33.17	None.	54.56	0.88	......	......
Fort Shaw, Mont	2.82	20.40	....	18.38	2.04	58.15	.58	0.45	......
Sunnyside, Wash	.52	25.57	Trace.	7.42	4.34	47.52	4.62	......	10.53
Yuma, Ariz	.14	24.40	Trace.	18.42	9.05	15.36	9.76	23.11	......
Roswell, N. Mex	.19	35.58	....	12.48	1.43	23.52	11.25	15.74	......
Montrose, Colo	.91	14.12	Trace.	22.70	5.68	55.65	1.85	......	......
Grand Junction, Colo	.78	26.83	Trace.	13.02	4.27	40.42	15.46	......	......
Huntington, Utah	.99	3.41	Trace.	36.14	3.55	56.60	.30	......	......

TABLE 7

Analyses of Seepage Waters Flowing Through Experimental Cement Tila Drains November, 1913

[Analyses of mineral matter in per cents]

Location	Per cent soluble solids	SiO_2	R_2O_3	CaO	MgO	Na_2O	Cl	SO_3	CO_2	Sediment
Garland, Wyo	0.499	0.88	0.10	5.40	3.00	35.00	2.97	49.32	3.55	Very small amount.
Fort Shaw, Mont. (station No. 2).	.649	.50	.07	4.66	6.71	31.28	1.82	51.23	3.85	Do.
Fort Shaw, Mont. (station No. 9).	.237	.96	.21	6.15	10.72	27.68	2.15	38.30	13.83	Do.
Sunnyside, Wash	.593	.84	.10	11.83	6.39	23.58	7.06	47.12	3.07	None.
Roswell, N. Mex. (station No. 11).	.531	.32	.09	20.22	3.97	19.16	22.63	30.52	3.03	Considerable.
Roswell, N. Mex. (station No. 17+74).	.525	.55	.11	14.95	4.69	23.76	27.58	26.02	2.31	Some.
Montrose, Colo	1.005	.32	.03	6.87	19.53	11.87	.49	57.95	2.97	None.
Grand Junction, Colo. (outlet).	1.165	.24	.08	7.14	7.34	27.93	24.82	32.02	.45	Do.
Huntington, Utah	.253	.76	.15	21.58	6.69	14.26	2.10	47.40	7.05	Considerable.
Yuma, Ariz. (upper end).	.090	3.68	.78	16.71	8.13	20.82	20.82	11.47	11.59	Very smal amount.
Grand Junction, Colo. (irrigation water; from irrigation canal).	.081	2.72	.12	13.86	5.80	23.90	22.03	22.03	9.53	Do.

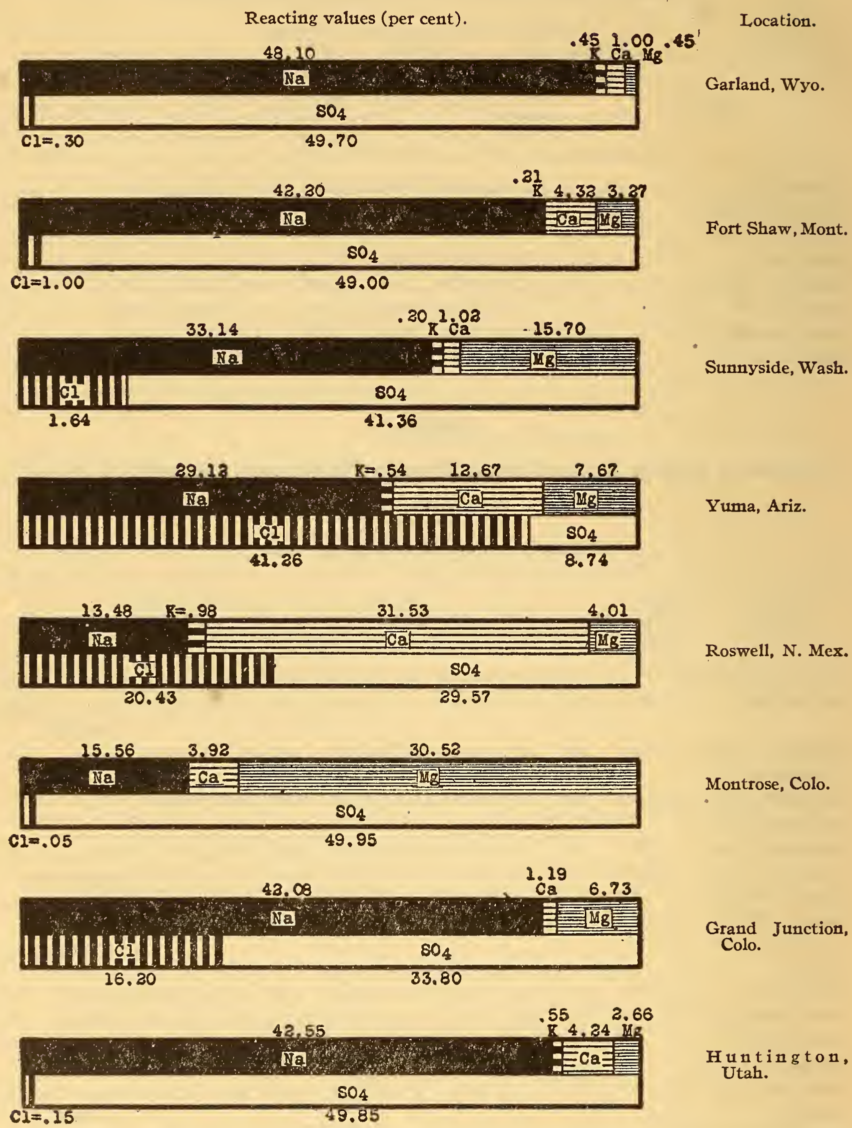

FIG. 15.—*Chemical analyses of alkali salts from surface of ground at site of experimental cement tile drains (1913). (Results given in Table 5)*

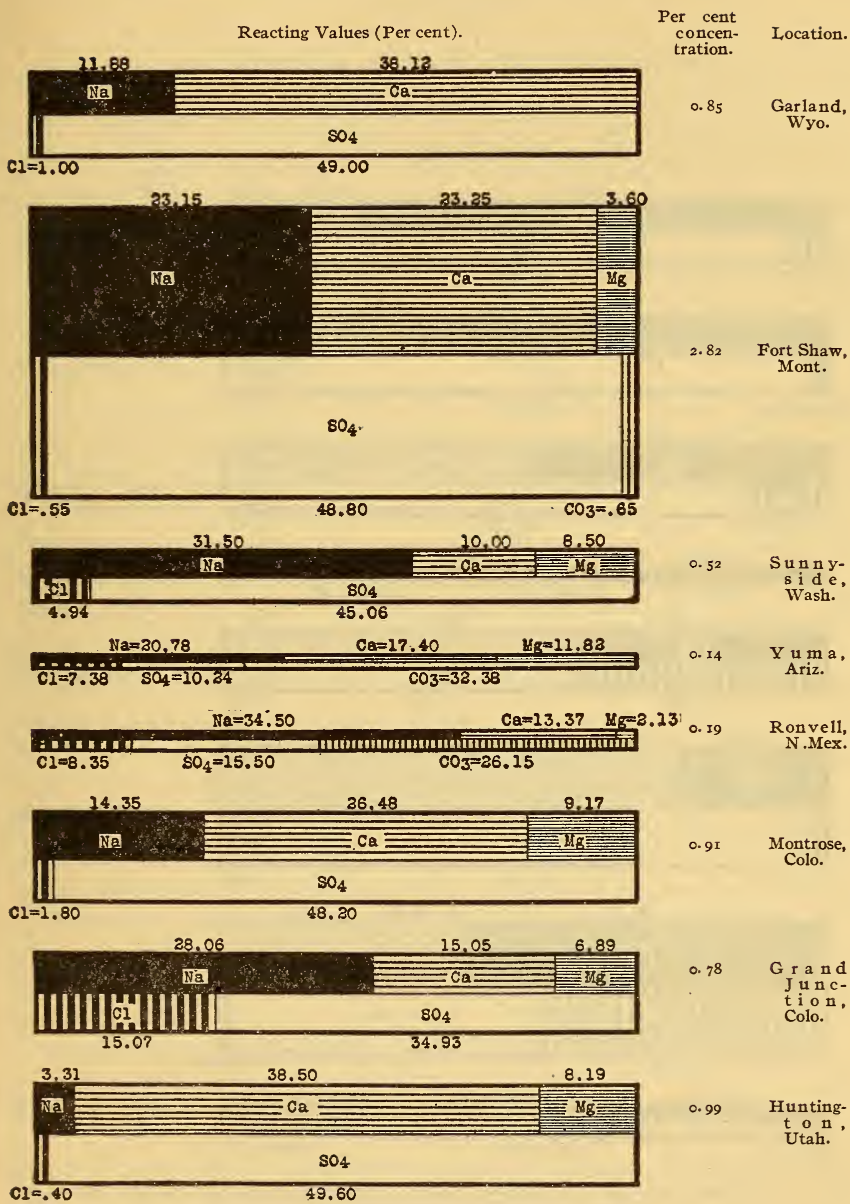

FIG. 16.—*Chemical analysis of soils at level of experimental tile drains (1913). (Results given in Table 6)*

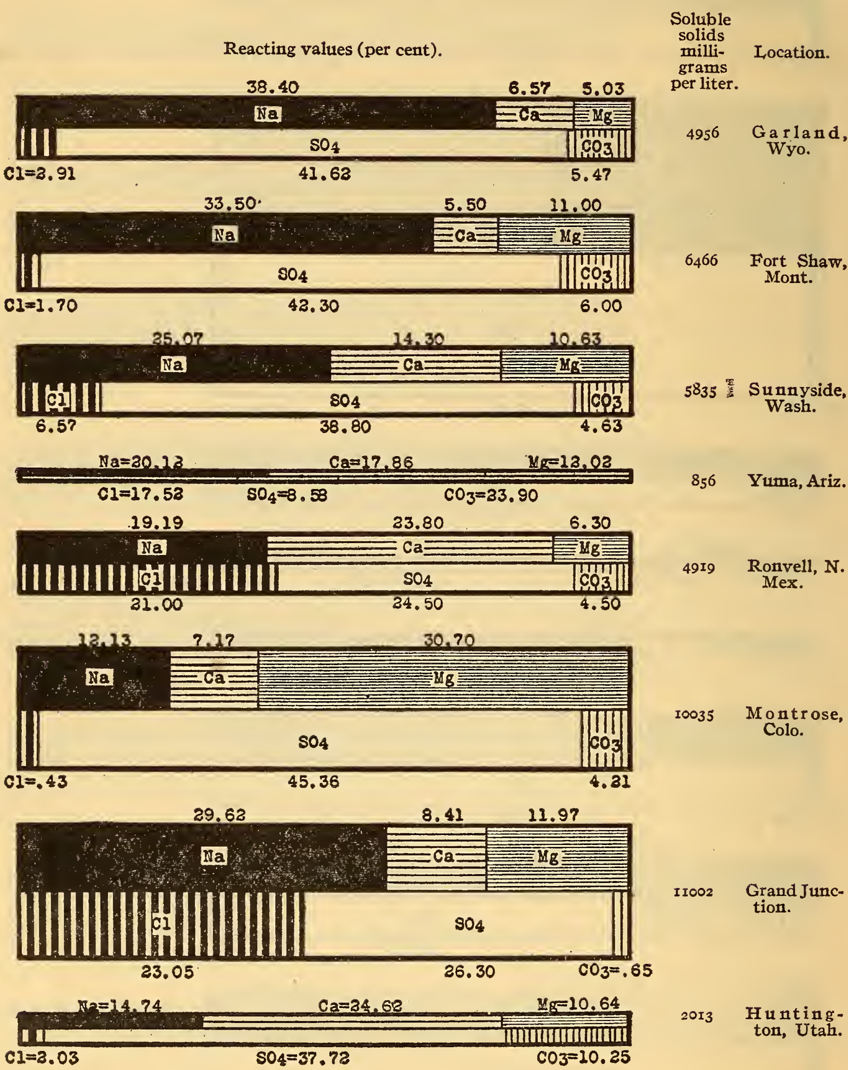

FIG. 17.—*Chemical analyses of seepage waters flowing through experimental cement tile drains (1913). (Results given in Table 7)*

3. PLACING

The tile were placed in such an order that sections containing two tile of each series could be removed at yearly intervals without disturbing the remainder of the line. Ten such sections, 32 feet long, were placed at one end of the line, and then all the tile remaining of each series were placed end to end in groups, commencing with series 1. This grouping is shown in Fig. 18. At Garland, Fort Shaw, Sunnyside, Yuma, and Roswell the "A" sections were placed at the upper end of the drain and the "B" sections at the outlet end. At the other points this arrangement of sections was reversed.

(*a*) GARLAND, WYO.—The drain was placed about 3½ miles southeast of Garland in a low section where alkali stood in layers an inch or more in thickness on the ground. Several concrete turnouts located near by in unused ditches were entirely disintegrated. As shown in Fig. 19, the lower end of the drain runs through a sandy soil and the upper end through coarse gravel, the grades being 0.022 and 0.010, respectively. The outlet is in an open ditch, which has a grade of 0.002. Since the oulet end for a distance of 200 feet lies above the frost line, a back fill was made, giving a minimum covering of 4 feet.

The tile were laid in cradles made of 2 by 4 inch side pieces and 1 by 4 inch cross pieces, on which the tile rested. Manholes were placed at stations 3+50 and 4+50, at an angle point and change of grade. At the time the tile were placed the groundwater plane was at the surface of the ground for the entire distance. Photographs were taken during the placing of the tile, which are shown in Figs. 20 and 21. The total fall in the line is 11 feet. Only three tile were broken or missing at Garland, the number being unusually low considering the length of the haul.

(*b*) FORT SHAW, MONT.—At Fort Shaw a location for the tile line was found just above an alkali lake, where the tile would also be of some service in draining an upper swamp which had ruined several farm units. The surface of the ground surrounding the lake and the site of the drain was incrusted with alkali one-eighth to one-fourth inch in thickness. Wooden silt boxes were placed at the upper end at station 6+00, where an angle was made.

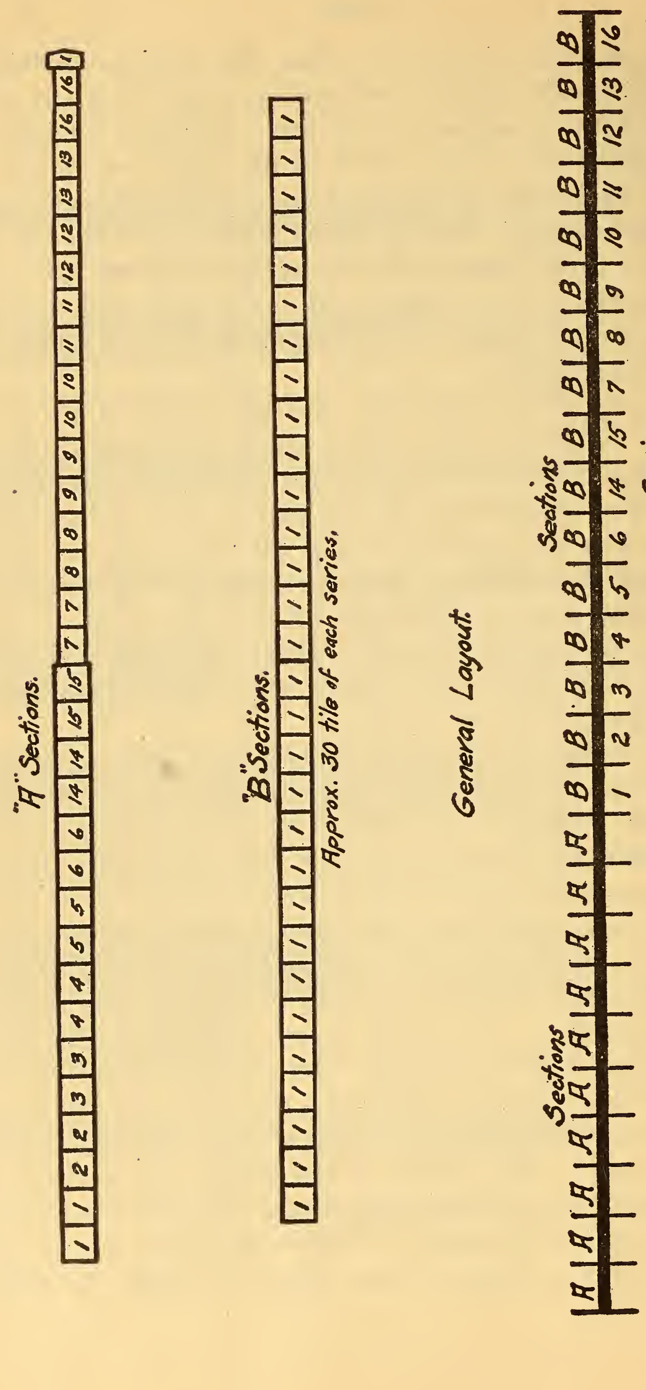

Fig. 18.—*Arrangement of drain tile. - The "A" sections contain two tile of each series and were thus arranged for convenience in removal for testing. There are 10 "A" sections followed by "B" sections each of which is composed of all the remaining tile of one type*

As the greater portion of the drain was located above the frost line, the refill was made to a depth of 4 feet wherever the cut was less than this amount. A portion of the line passed through hard cemented gravel, which gave considerable trouble in digging. The upper 400 feet of the line was given a grade of 0.021 and the lower 200 feet a grade of 0.004, the outlet being into an open ditch which emptied into the alkali lake 200 feet below the tile line. Three tile were broken in this shipment. Figs. 22, 23, and 24 show the location of this drain.

(*c*) HUNTINGTON, UTAH.—At Huntington the tile drain was installed on private land about 1 mile south of town. Wooden box drains, without bottoms, had been placed in this ground about eight years before, and as these boxes were filled and badly off grade it was decided to replace them with cement tile.

As shown in Fig. 25 the line of the old wooden drain was not closely followed, but an offset was made and the old line paralleled. The trench varied in depth from 4½ to 6 feet, passing through a soil uniform in color and appearance, and acting much like quicksand in the bottom, due to the excess of water. The digging was very easy, requiring no picks or spades but only round-pointed long-handled shovels. The drain was laid with a fall of approximately 1 foot per 100 feet. In the portion of the trench which followed the old box drains the tile were supported on boards 1 inch by 6 inch by 12 feet on account of the soft bottom. Figs. 26 and 27 show the conditions near the site of the drain.

On account of rains preceding the installation of the experimental tile, the white surface of this and the surrounding land was not so apparent, but in spots large white patches could be seen. Land to the west and slightly higher than that on which the tile were placed was very wet and sandstone bowlders lying on the surface were badly cracked and disintegrated, apparently due to the crystallization of the alkali in their pores.

As Huntington is located about 23 miles from the railroad it was necessary to haul the tile from Price, Utah. The number of tile broken was 18, confined mostly to the handling on the railroad as only 4 tile were broken in the 24-mile haul from Price.

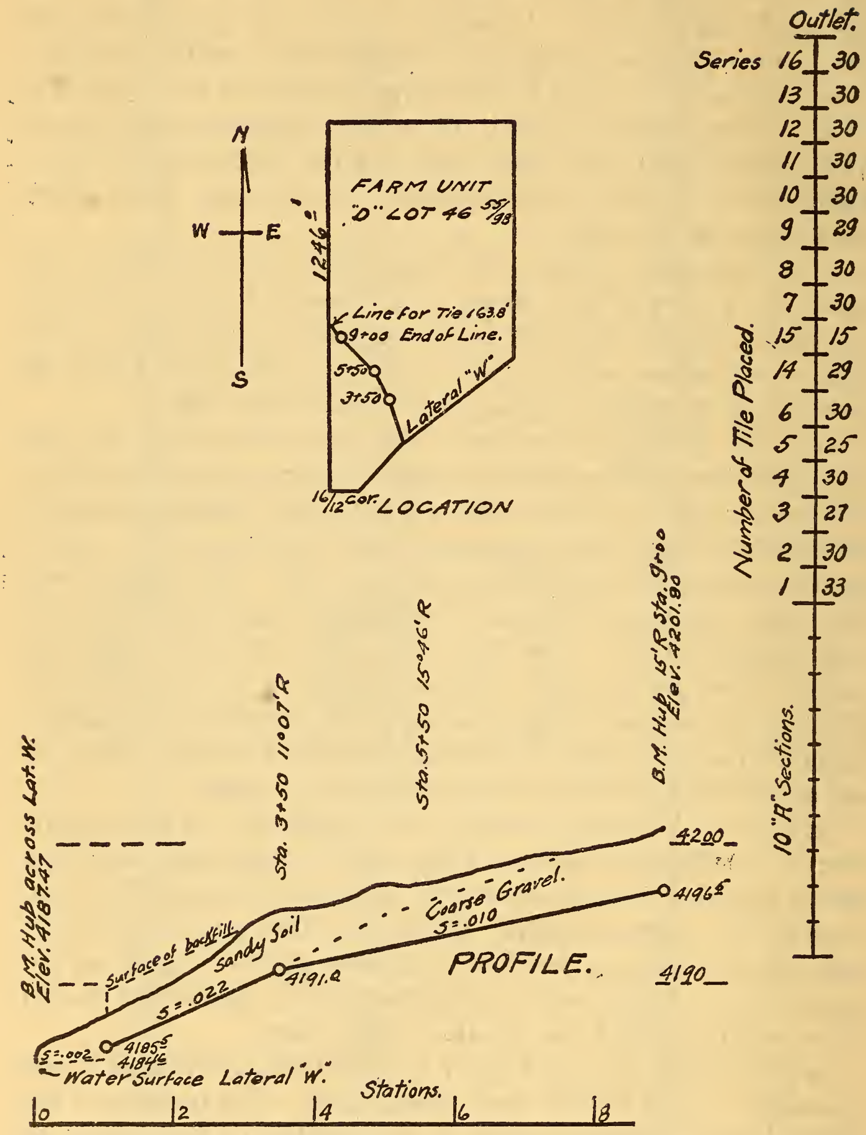

Fig. 19.—*Showing location, plan, profile, and arrangement of experimental drain tile at Garland, Wyo.*

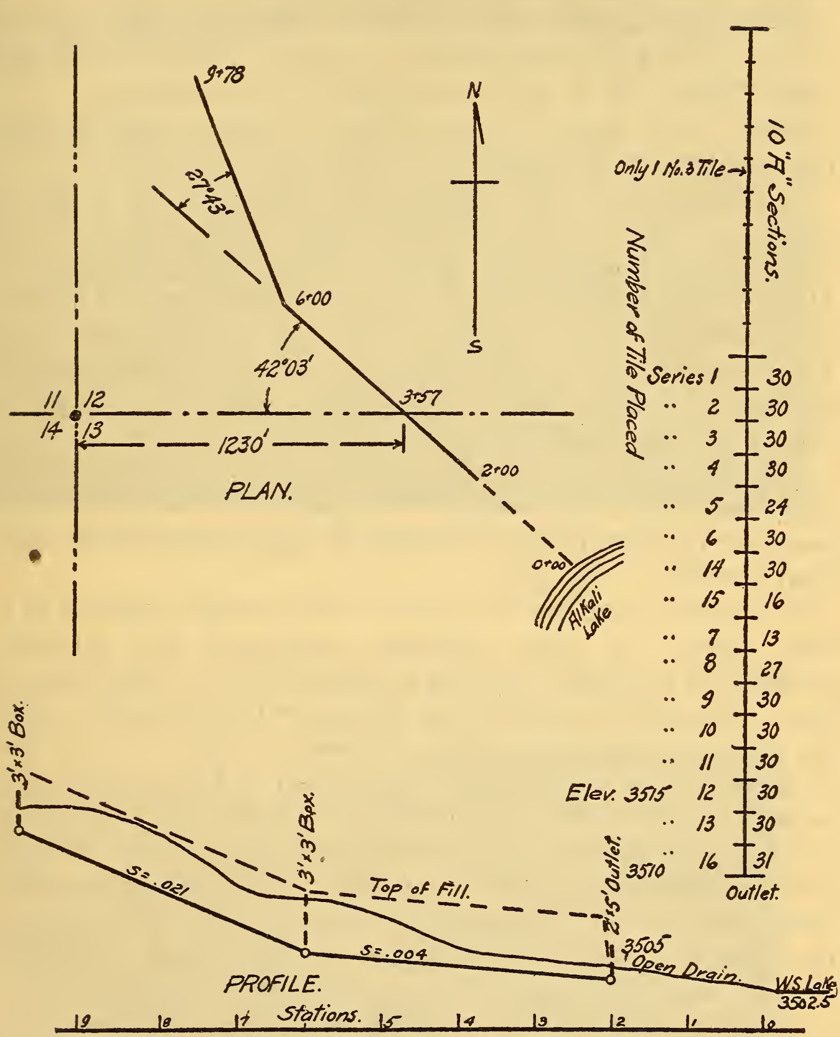

FIG. 22.—*Showing location, plan, profile, and arrangement of experimental drain tile at Fort Shaw, Mont.*

(*d*) Sunnyside, Wash.—At Sunnyside the tile were installed on private land about 1 mile from town. The trench at the lower end was about 6 feet deep and 4½ feet deep at the upper end. At the lower end the soil was very sandy. The water table was low at the time the tile were placed. A uniform grade of 0.002 was used. There was a loss of eight tile in this shipment. The location of this drain is shown in Fig. 28. Figs. 29 and 30 show the conditions at this point.

(*e*) Yuma, Ariz.—The installation at Yuma was made in the southeast corner of the experiment farm of the United States Department of Agriculture on the Yuma Indian Reservation. The drain follows the line of an old slough and is exposed to concentrated alkali water. The wagon haul to this point was about 2 miles and the total number of tile lost, including railroad breakage, was 18. Fig. 31 shows the location of this drain. Figs. 32 and 33 show the installation of the drain.

(*f*) Roswell, N. Mex.—The installation at Roswell was made on private land 4 miles east and 1½ miles north of Roswell on the northeast quarter of sec. 25, T. 10 S., R. 24 E., New Mexico principal meridian. (Fig. 34.)

The outlet of the line was placed in the wooden manhole of a drain which had been previously constructed and extended northeast in a straight line with a uniform rise of 0.1 foot per 100 feet. The depth averaged about 6.5 feet, with the exception that the upper 150 feet had a depth of about 5.5 feet. During the installation the ground water stood about 4 feet above grade, causing the sides of the trench to cave unless well braced. A wooden manhole was placed at the end of the tenth "A" section, and an observation well at the upper end of the line. Three tile were found broken in the car and one was broken in hauling to the drain site, so that the breakage was approximately one-half of 1 per cent. Fig. 35 shows the work in progress at Roswell.

(*g*) Grand Junction, Colo.—The tile at Grand Junction were placed on a 10-acre tract of land included in the McKinney experimental farm, one-fourth mile south of the old United States Indian school just east of the city. (See Fig. 36.) The land of which this tract is a part is being improved under the supervision

FIG. 23.—*Alkali Lake at lower end of experimental drain at Fort Shaw, Mont., showing the heavy alkali deposits surrounding the lake*

FIG. 24.—*Site of experimental drain at Fort Shaw, Mont., looking toward lower end, showing the partially excavated trench and alkaline seepage water collecting in the bottom; also alkali weed covering the site*

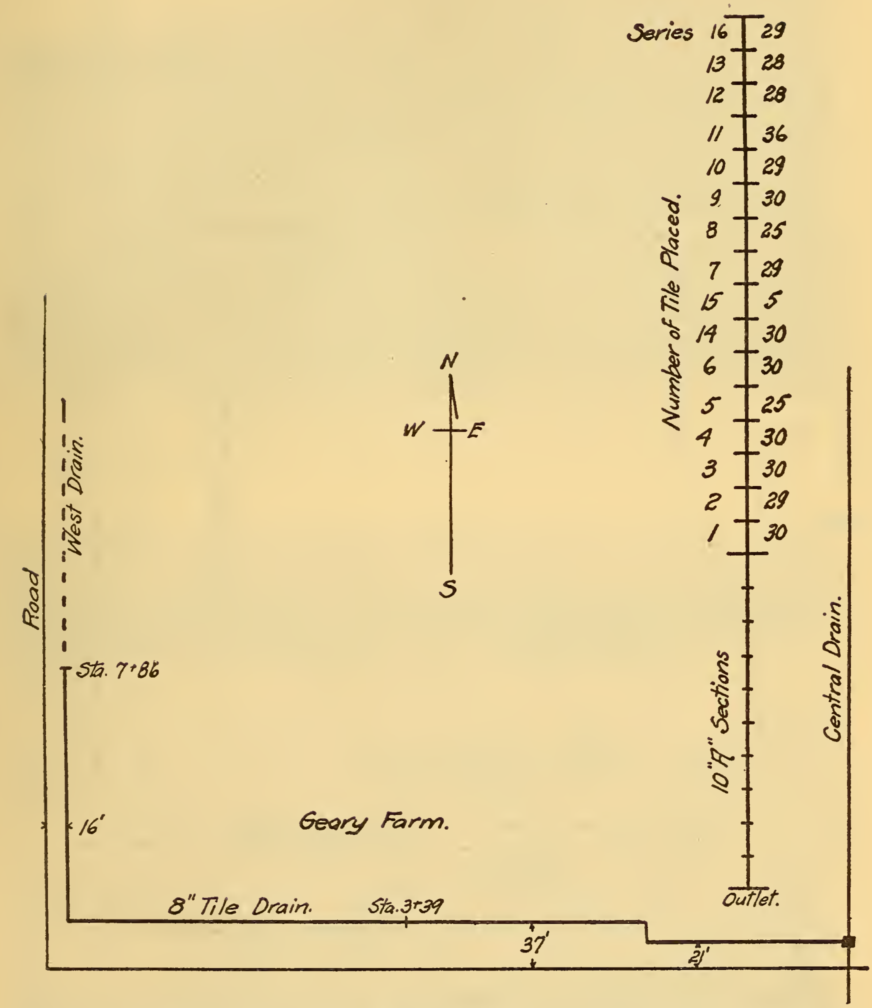

FIG. 25.—*Showing location, plan, and arrangement of experimental drain tile at Huntington, Utah*

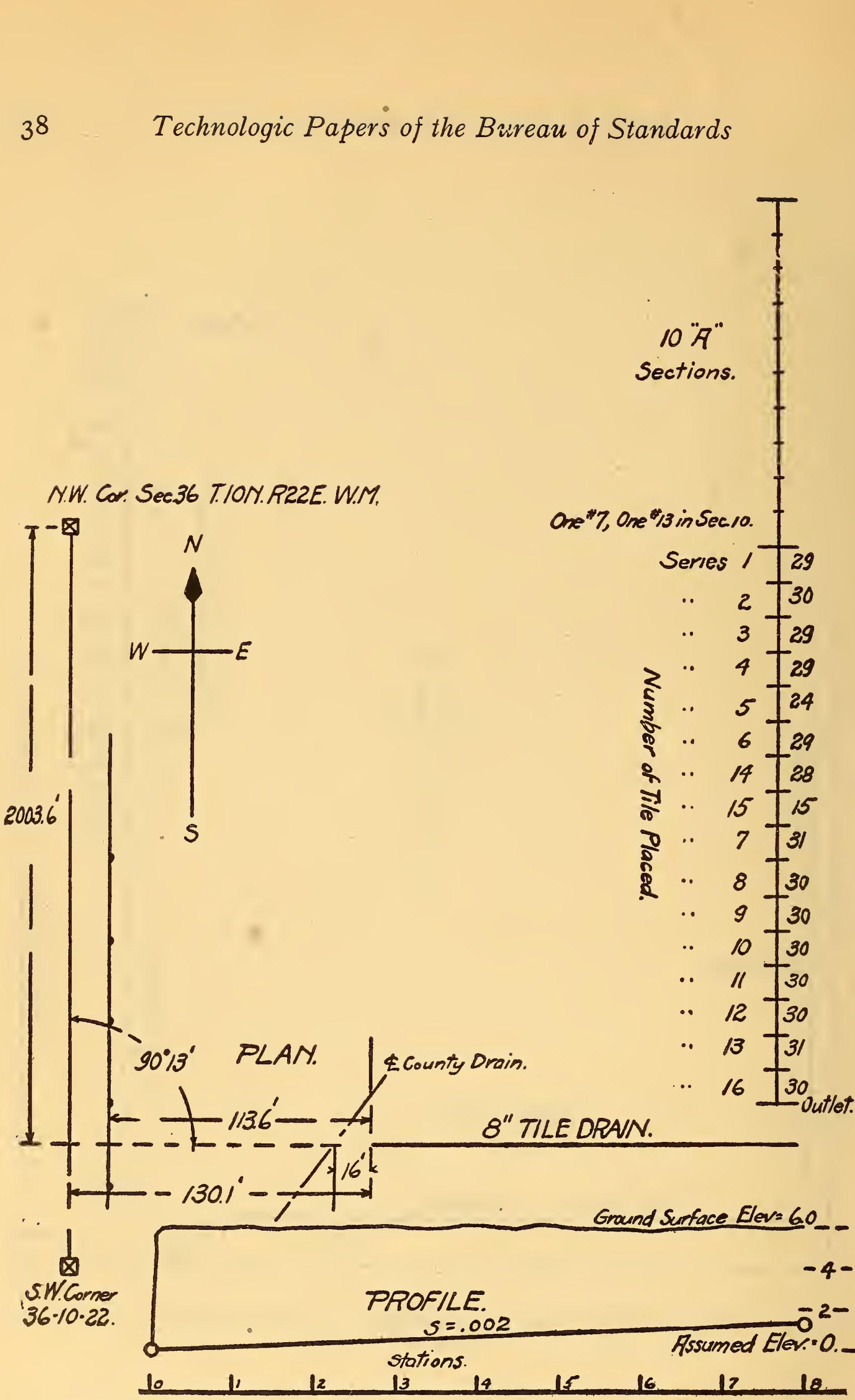

FIG. 28.—*Showing location, plan, profile, and arrangement of experimental drain tile at Sunnyside, Wash.*

Fig. 26.—*Opened ditch for experimental drain at Huntington, Utah, showing the character of the soil, lack of vegetation due to alkali salts, and the approximate depth of excavation*

Fig. 27.—*Bank of waste ditch, showing heavy white incrustation of alkali salts at Huntington, Utah. The concentration of alkali salts in this locality is probably as great as will be found in the State*

Fig. 29.—*Opening lower end of ditch for experimental drain at Sunnyside, Wash., showing partially excavated trench. Note amount of vegetation as compared with that in Fig. 27*

Fig. 30.—*Upper end of site of experimental drain at Sunnyside, Wash., showing lack of vegetation and heavy alkali crust on surface of ground. The salts appear much more concentrated on the surface at the upper end than at the lower end. While there are scattered deposits of salts on the surface over the site, conditions do not appear as bad as upon some of the other projects*

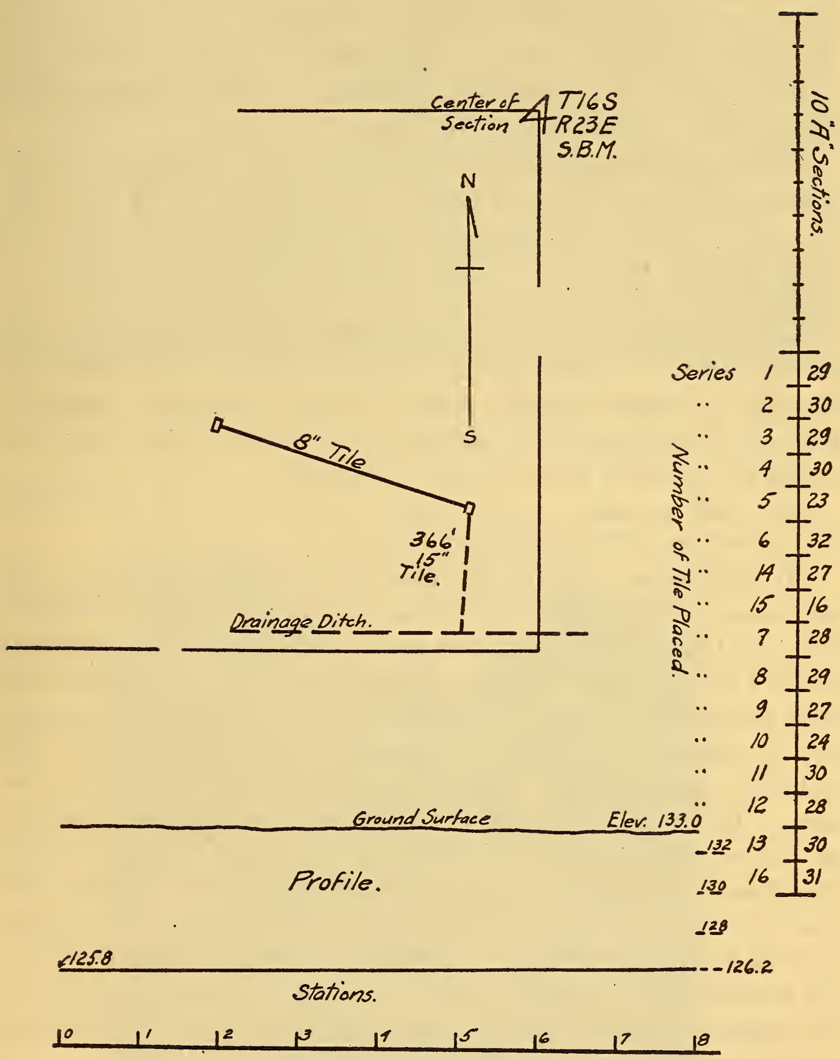

FIG. 31.—*Showing location, plan, profile, and arrangement of experimental drain tile at Yuma, Ariz.*

of drainage investigations, Department of Agriculture. This land had previously been irrigated and cultivated, but was later abandoned on account of the concentration of alkali on the surface and in the upper part of the soil. At the time the experimental tile were placed the surface was entirely covered with a thick white coating of alkali salts, as shown in the accompanying photographs. (See Figs. 37 and 38.)

The trench was excavated to a depth of 5½ to 6½ feet, the lower portion being very wet and mucky, requiring heavy sheeting and bracing which interfered greatly with the work of excavation and made progress very slow. (See Fig. 39.) The tile were laid on a grade of 0.3 foot per hundred feet.

The drain empties into a large wood silt basin which is a part of the system of drains of an adjacent 10-acre tract. Although the line is straight without bends, another basin was placed at the end of the tenth "A" section and also one at the upper end to aid in observing the working of the drain.

The total breakage in this shipment was nine tile, four being found broken while unloading the car.

(*h*) Montrose, Colo.—The point selected for placing the tile was about 12 miles from Montrose on "seep" land near milepost No. 6 and below the level of the South Canal on the Uncompahgre Project of the United States Reclamation Service. The soil consists of adobe and shale. This shale becomes very hard when dry and is difficult to excavate. The upper end of the tile line was entirely through shale. The amount of water flowing in the bottom of the trench was small, being as great near the upper end as at the outlet, indicating that most of the seepage occurs through the shale. Seepage was small in amount because the canal had been emptied previous to the excavation of the ditch for the experimental drain, but during the summer months the seepage should be considerably increased, as the change from concrete-lined to the unlined canal, whose maximum capacity is 1300 second-feet, is made opposite the upper end of the tile line.

The breakage of tile at this point was the maximum, 22 tile being damaged in the railroad and wagon haul. A 12-foot wooden box was placed at the outlet and wooden silt boxes at the two

FIG. 32.—*View from upper end of opened ditch for experimental drain at Yuma, Ariz., showing tile laid along the ditch ready for placing. There is only little alkali salt visible on the surface at this site, and conditions do not appear to be as severe as on many of the other projects, although the salts perhaps are of the worst character*

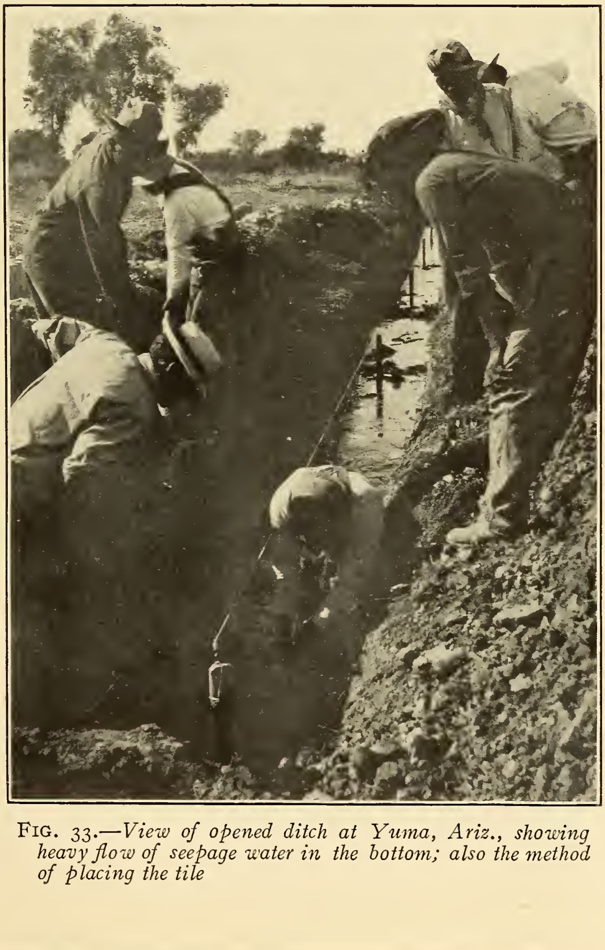

FIG. 33.—*View of opened ditch at Yuma, Ariz., showing heavy flow of seepage water in the bottom; also the method of placing the tile*

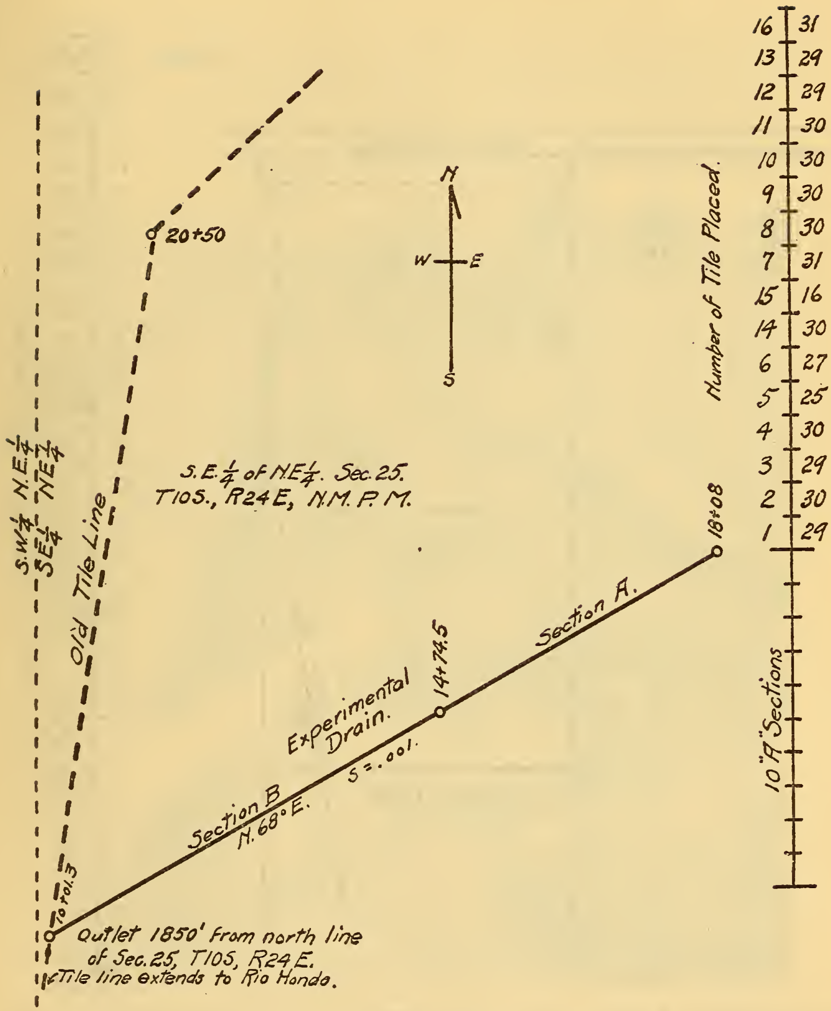

FIG. 34.—*Showing location, plan, and arrangement of experimental drain tile at Roswell, N. Mex.*

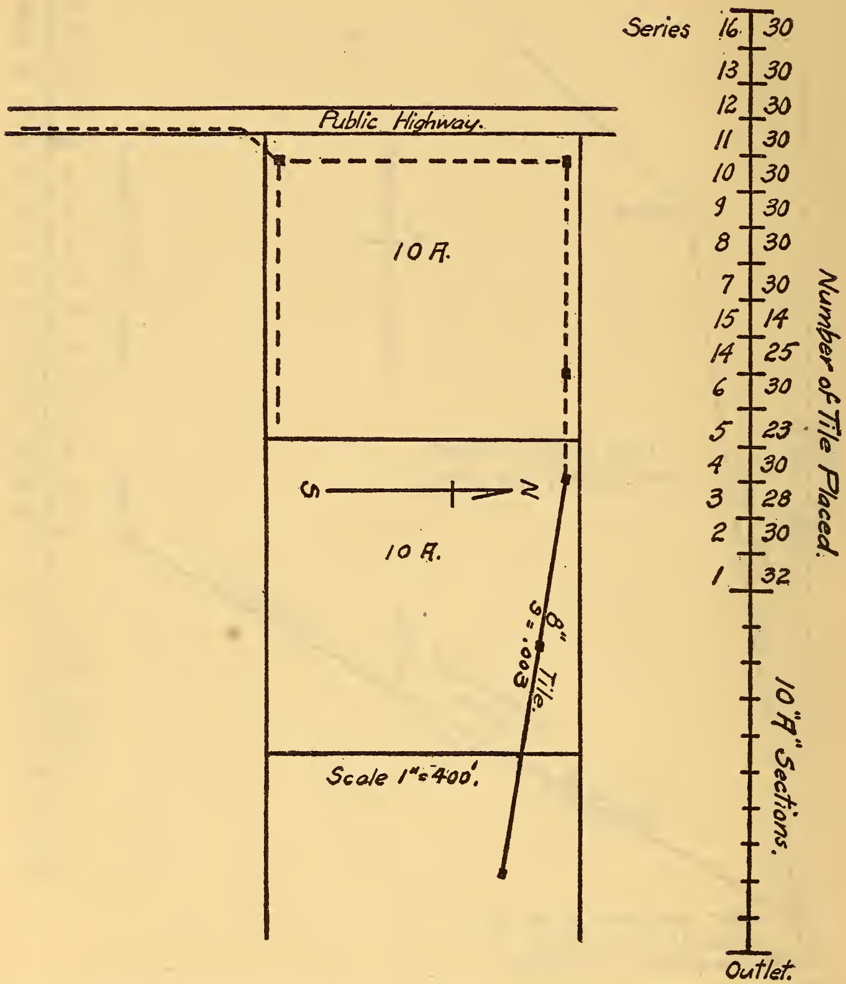

FIG. 36.—*Showing location, plan, and arrangement of experimental drain tile at Grand Junction, Colo.*

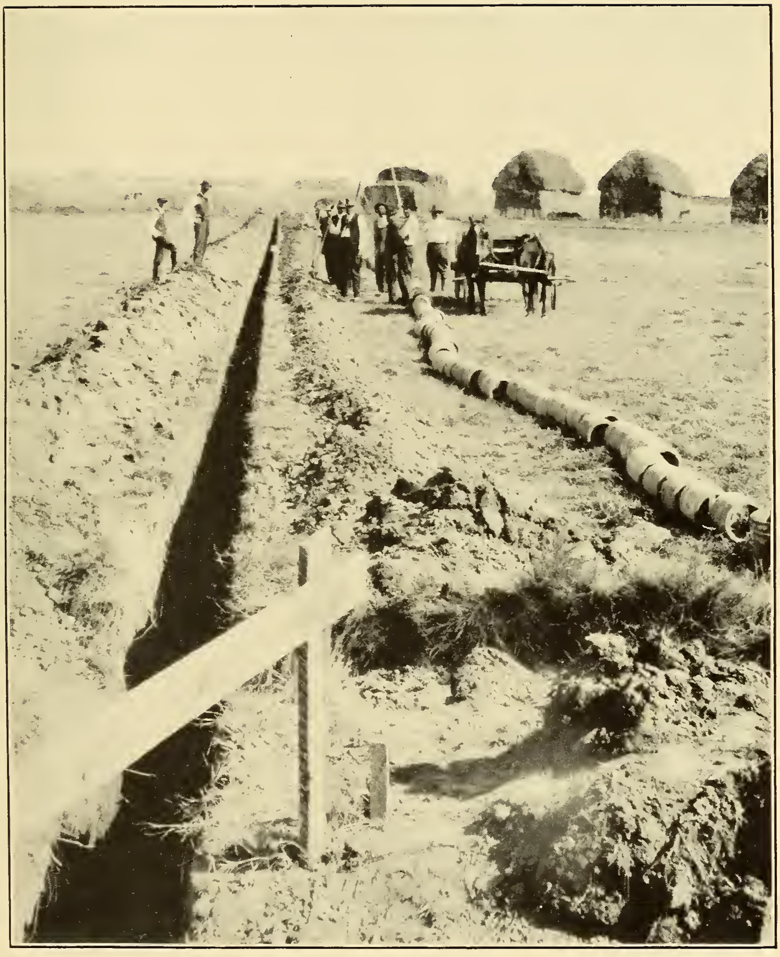

FIG. 35.—*View from lower end of opened ditch for experimental drain at Roswell, N. Mex., showing tile strewn ready for placing. Note the entire trench is partly excavated and banks are vertical. The concentration of salts is not as great at this project as at some of the others*

FIG. 37.—*View of site of experimental drain at Grand Junction, Colo., showing extremely heavy concentration of alkali salts on the surface of the ground. There is practically no vegetation other than alkali weed. Observe the salts are more concentrated on the high spots*

FIG. 38.—*Site of experimental drain at Grand Junction, Colo., showing heavy alkali deposit. The tile have been strewn ready for placing. Note lack of vegetation*

FIG. 39.—*Opened ditch for experimental drain at Grand Junction, Colo., showing the difficulties encountered in placing the tile. Observe the caving banks and timber bracing required*

angles, at stations 2+60 and 5+35. From stations 1+92 to 2+42 and 2+75 to 3+07 the tile were laid on boards in the bottom of the trench. The location of this drain is shown in Figs. 40, 41, and 42.

(*i*) COLUMBIA, MO.—The experimental drain at Columbia was placed on land belonging to and being farmed by the University of Missouri Agricultural School, about one-half mile south of the campus. The line, which has a total fall of about 24 feet, follows the line of a small channel which has been cut by surface water. The depth of the tile below the surface is small, as shown in Figs. 43 and 44, but it is sufficient to protect the line from frost action. The upper 12 or 15 inches is black soil and rather easy to dig, with the exception of a short length through the ridge at station 2+00, where some rocks were found. The soil was moist, but no stream of water was developed during the trenching. A wooden-box outlet was placed at the lower end where the earth covering was shallow.

The total breakage in the shipment of tile to this point was 22.

(*j*) CROOKSTON, MINN.—The tile shipped to Crookston were installed in a 40-acre tract of pasture land, which is part of the land belonging to the "Northwest Agricultural School" of the University of Minnesota, which is located about 1½ miles north of Crookston. This region is very flat and has very little natural surface drainage, being made up mainly of small ridges and depressions varying only a few feet in elevation. The flatness of the country, of which this farm is one of the lowest areas, is shown by the results of a topographical survey, which indicates that in the 476 acres included in this farm the greatest difference in elevation is about 2 feet.

The soil is mainly a clayey loam, the upper few inches being black, the lower sections yellow, but of about the same composition. The black soil appears to be deeper in the depressions. Scattered deposits of alkali salts can be found in the elevations. At the time the trench was dug the soil was quite moist and sticky, and was removed from the spade with difficulty. The lower foot was harder and drier and even more difficult to dig.

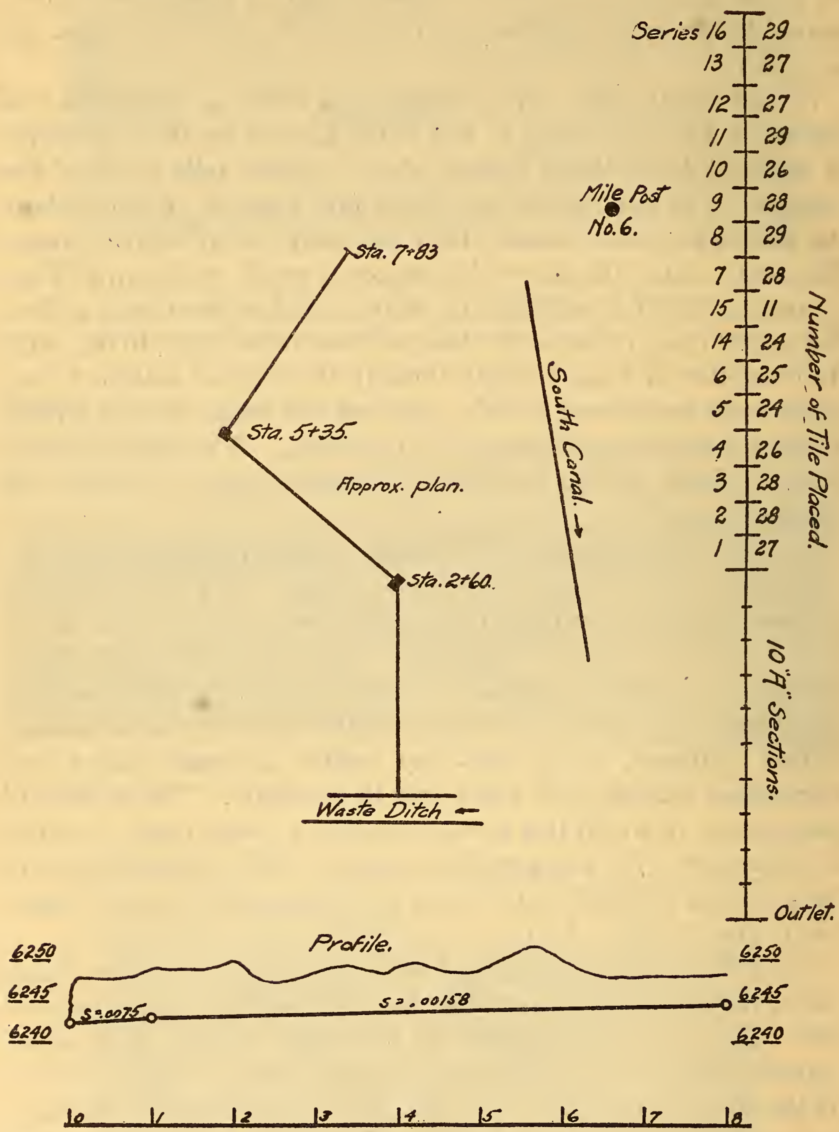

FIG. 40.—*Showing location, plan, profile, and arrangement of experimental drain tile at Montrose, Colo.*

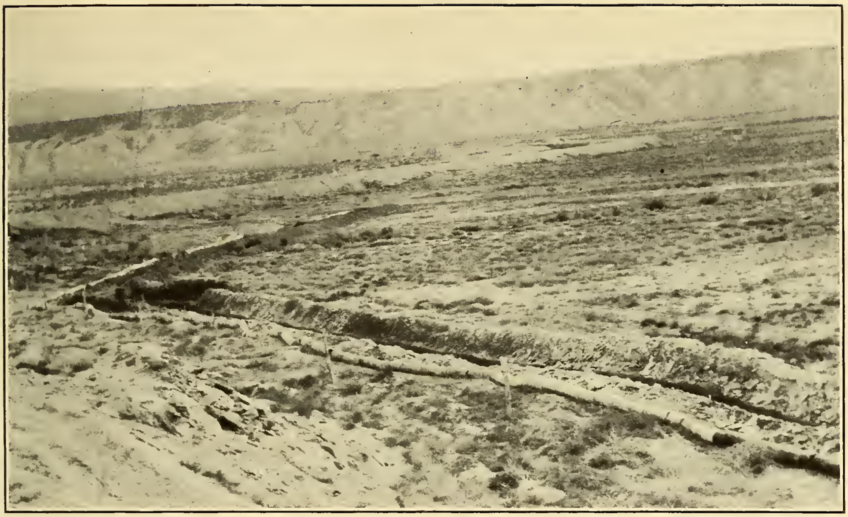

Fig. 41.—*View from upper end of site of experimental drain at Montrose, Colo., showing the opened ditch and the distribution of the tiles just previous to placing. Observe hard shale excavated at upper end to the right in picture*

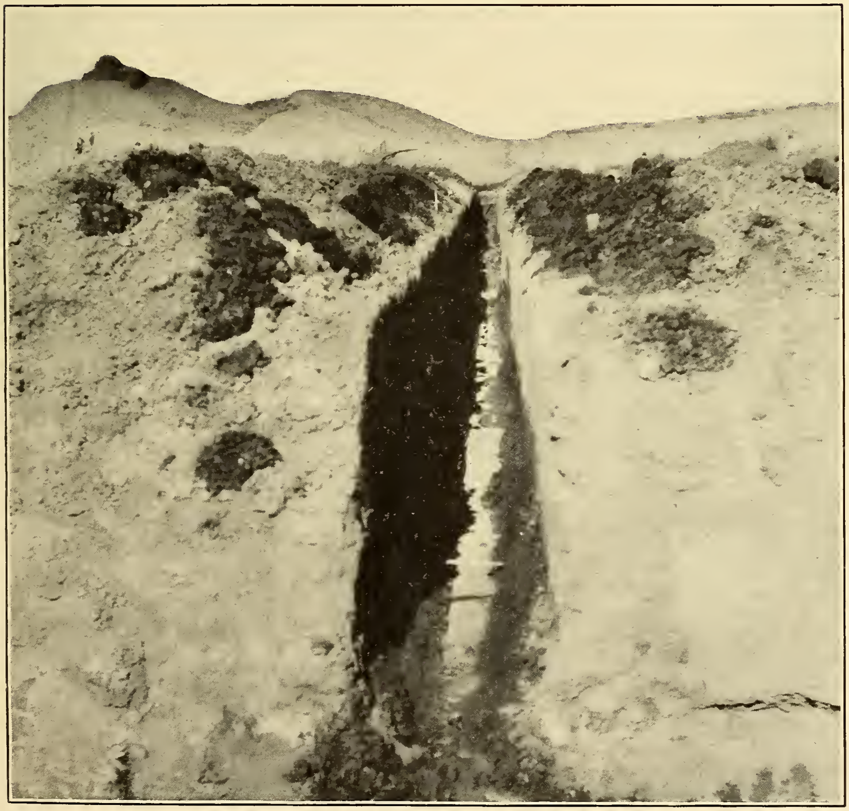

Fig. 42.—*Lower end of opened ditch for experimental drain at Montrose, Colo., showing depth of completed trench, flow of seepage water, and alkali salts on surface of soil where partially dried in the foreground*

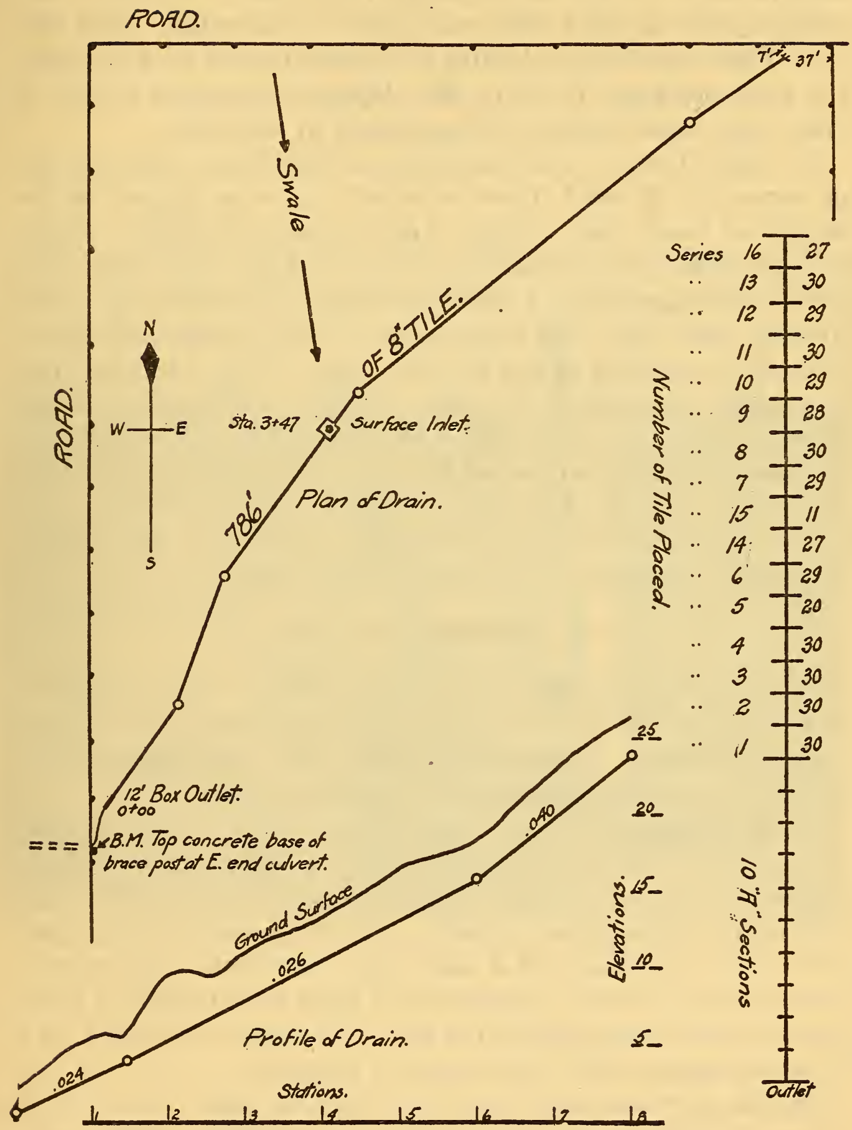

FIG. 43.—*Showing location, plan, profile, and arrangement of experimental drain tile at Columbia, Mo.*

As shown in Fig. 45 the tile were placed quite shallow, with a uniform fall of 0.8 foot in the length of 800 feet. A wooden box emptying into an open ditch was placed at the outlet. (See Fig. 46.) There was no flow of water at the time the tile were installed. The total breakage in tile in this shipment amounted to six, of which three were broken in being hauled to the ditch.

(*k*) Ames, Iowa.—A car containing 48 tile of each series, excepting series 15, of which there were only 42, was shipped to the campus of Iowa State College, Ames, Iowa, for storage. These tile were piled on wooden strips so as to keep them above the surface of the ground. A more careful account was made of the breakage here than had been made of the previous shipments. Although no packing of any kind was used and the tile were piled to a height varying from four high at the ends to two high at the doorway of the car, only three tile were broken. When the car was opened, the tile were found arranged just as placed at the time of loading. The breakage was confined to the lower layers near the car sides, indicating that the damage was due to the wedging of the tile, caused by movement of the car sides.

V. TESTING OF TILE

The first physical tests of the tile were made in 1914, about one year after the tile were placed. A representative of the Bureau visited all projects, where two tile of each type were removed from each drain and tested immediately upon removal.

A small portable machine was designed (Fig. 47) which could be transported to the site of the drains. This machine with all accessories and trunk for carrying weighed 170 pounds. The machine is of 3800-pound capacity, of the three-edge bearing type, and consists essentially of a steel angle iron frame supporting a hydraulic press which is operated by a hand lever through a worm gear and screw for applying the load. The load is recorded on a hydraulic gauge which can be read to 5 pounds.

The tile were uncovered and taken from the ditch one or two at a time, cleaned, measured, and tested immediately. Notes were made on the length and thickness of the tile at each end; also its condition if in any way abnormal. The tile were placed in the

FIG. 44.—*Lower end of experimental drain, Columbia, Mo., showing shallow installation of tile necessary on account of high outlet*

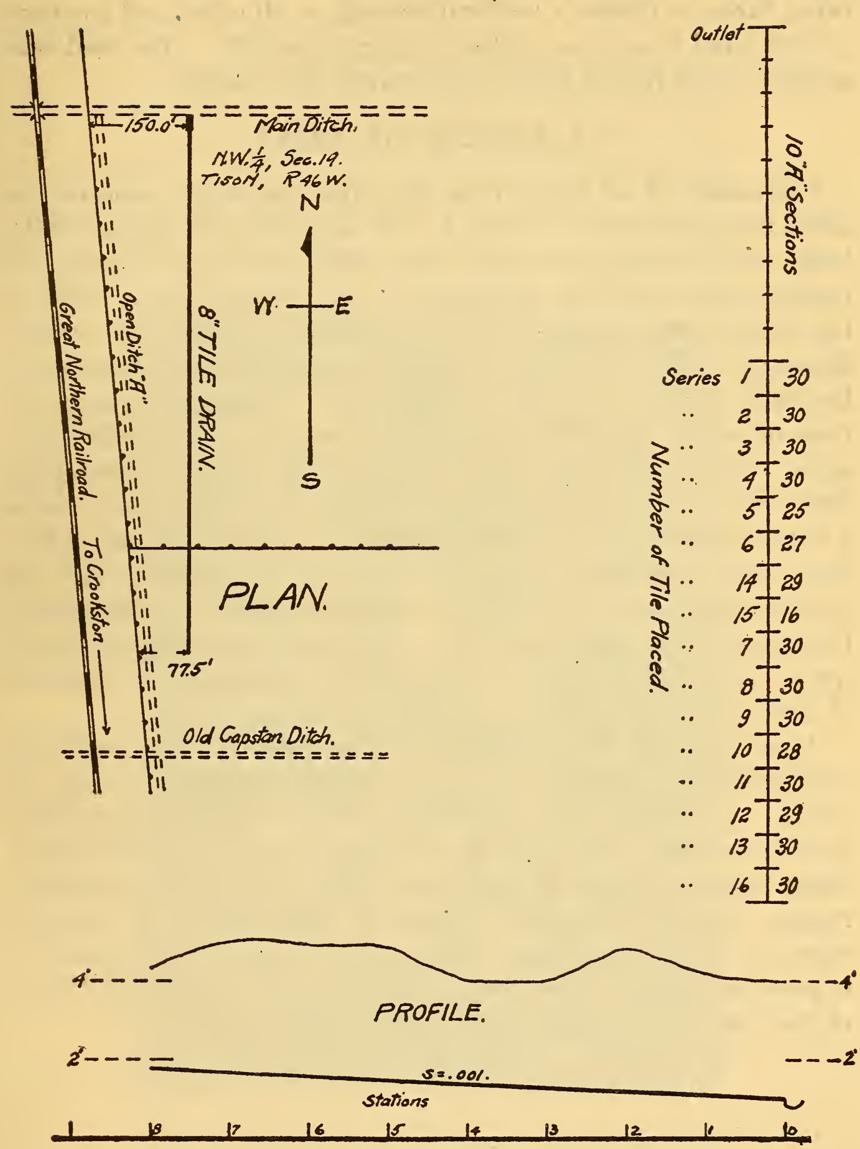

FIG. 45.—*Showing location, plan, profile, and arrangement of experimental drain tile at Crookston, Minn.*

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machine in the same relative position as found in the ditch, care being taken to obtain a uniform bearing on all edges and to operate the hand lever at as uniform a rate as possible. The load was applied at the rate of about 1500 pounds per minute.

VI. RESULTS OF TESTS

The results of all tests of the tile after one year's exposure in alkali soils are given in Table 8. To determine the approximate loads which these tile would have withstood in the trench the results given should be multiplied by the constant 1.50, which is the factor recommended by the American Society for Testing Materials. The results as a whole are quite uniform and compare favorably with other tests of drain tile. Occasionally results of tests of similar tile differ by 30 or 40 per cent, but usually they agree within a few per cent. It should be borne in mind that these tile are exposed to abnormal conditions, which may cause a variation in results of tests of apparently similar tile only a few feet apart in the same ditch. No general conclusions should be drawn from the results of this investigation until it has progressed for several years and tests have been made of a sufficient number of tile of each type to confirm beyond question the behavior of each particular type.

A summary of the results is given in Table 9. The results of tests included in Table 9, are shown diagrammatically in Figs. 48 and 49. It should be emphasized that the breaking tests alone should not be taken as an index of the resistance of the tile to alkali action, as some of those which had a normal or only slightly reduced strength showed evidence of alkali action by softened edges or cracked surfaces. Where such action has been noted it is possible another year or two of exposure may cause the failure of the tile although this need not necessarily result.

FIG. 46.—*Lower end of experimental drain at Crookston, Minn., showing shallow installation of tile with box at outlet to prevent tile being washed out*

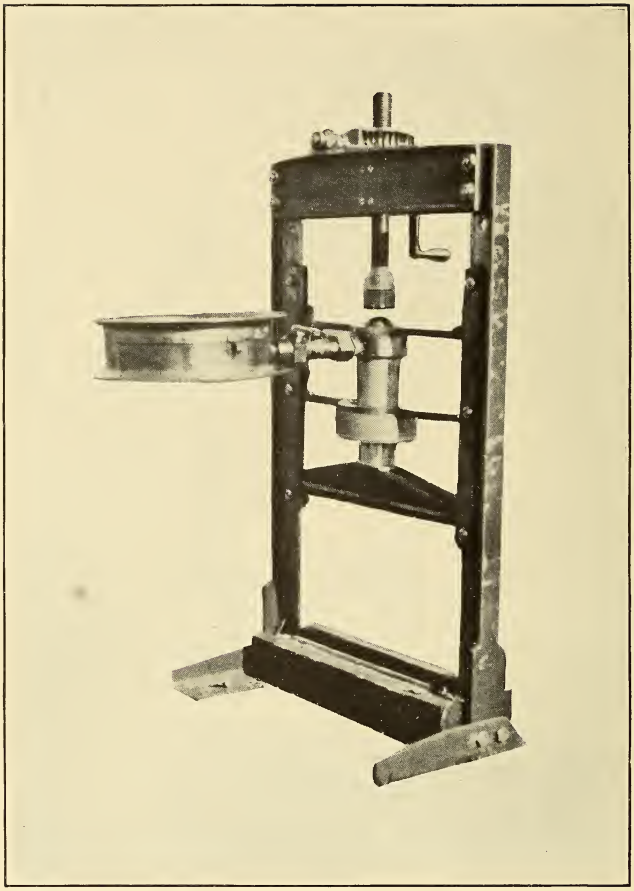

FIG. 47.—*Portable tile-testing machine of three-edge bearing type used in testing experimental tile at the site of the drain. The pressure applied to the tile through the worm gear and screw is measured in the hydraulic gauge which is attached to the ram*

TABLE 8

Complete Results of Tests of Experimental Cement Drain Tile (1914)

[Total breaking load in pounds]

Exposure	Location	Tile series No. —															
		1		2		3		4		5		6		14		15	
		a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b
Atmosphere.[a]	Ames, Iowa...	2825		2425		2395		1955		2905		2140		2030		1275	
		2895		2895		2130		2045		3220		3150		2670		2045	
		3195		2660		1990		2950		3105		2320		2275		1530	
Fresh water.	Columbia, Mo	2705	2670	2600	2385	2480	2690	2725	2615	2140	2555	2535	2750	2555	2340	1615	1515
	Crookston, Minn.	2579	2759	2748	3085	2770	3231	[b]2394	2951	2181	2592	2883	2523	2782	2748	1319	1770
Alkali water.	Garland, Wyo	3390	3175	3030	2885	1945	[c]3365	2680	2750	2645	2750	2340	1910	2770	2435	1595	1375
	Fort Shaw, Mont.	2780	2470	2490	2570	2680	2525	1825	2350	1900	3105	[d]2545	[d]3715	2670	2995	1385	1680
	Sunnyside, Wash.	2645	2460	3005	3285	2570	[b]1980	2320	2840	2415	2660	2350	1910	2360	2635	1375	1375
	Yuma, Ariz...	2570	3420	2860	3120	2350	2160	2500	2375	2075	2350	1910	2340	2535	2660	1715	1550
	Roswell, N. Mex.	2385	3050	3590	2690	2840	2490	2645	2425	2470	3230	2985	[b]2010	2750	2525	1750	1470
	Montrose, Colo	2870	2715	3075	3030	2200	2360	2940	3500	3150	3150	2245	2795	2705	2905	[e]1220	1220
	Grand Junction, Colo.	2590	2670	2815	2975	2885	[f]1375	2130	2555	2055	2115	2045	2960	2265	3175	[e]1625	[e]1855
	Huntington, Utah.	[i]2435	2105	3330	3580	1530	1825	3465	2985	2770	2645	[g]1485	[h]1440	2770	2905	1725	2105

[a] Tests were made at Ames following a heavy rain to which the tile had been exposed.
[b] Fractured surfaces showed poor tamping of walls.
[c] Heavy, crusty, white deposit on outer bottom surface. Apparently did not penetrate into wall.
[d] White deposit on outer surface near one end of tile.
[e] Soft spot on outer surface at end of tile.
[f] Fractured surface white.
[g] Circumferential crack apparent after breaking.
[h] Two longitudinal cracks and circumferential cracks at ends.
[i] Long crack previous to testing. Crack placed so as to be at eighth point in machine.

TABLE 8—Continued

Exposure	Location	Tile series No. — 7 a	7 b	8 a	8 b	9 a	9 b	10 a	10 b	11 a	11 b	12 a	12 b	13 a	13 b	16 a	16 b
Atmosphere.[a]	Ames, Iowa	1265		940		1570		1540		1255		1100		1385		1185	
		1165		860		1485		1310		1120		1130		1185		1100	
		1385		1035		1945		1440		1360		1055		1450		1350	
Fresh water.	Columbia, M	1210	1145	1075	970	1530	1705	1695	1870	[b]1200	1200	1145	1200	1460	1485	1000	1155
	Crookston, Minn	1517	1417	950	1044	1660	1506	1770	1857	1275	1439	920	1154	1472	1406	1000	880
Alkali water.	Garland, Wyo	1200	1605	770	820	1570	1440	1145	1090	1255	1275	570	730	1285	1000	660	720
	Fort Shaw, Mont	1185	1310	1185	910	1625	1485	1550	1515	1495	1360	1045	980	1045	1375	1020	940
	Sunnyside, Wash	900	1320	980	990	1870	1585	1640	1750	1110	1595	1035	1035	1625	1265	1055	950
	Yuma, Ariz	1505	1255	1054	1090	1715	1650	1640	1980	1340	1395	910	1055	1185	1200	1000	1100
	Roswell, N. Mex	1175	1470	980	1100	1450	1660	1605	1185	1495	1375	1255	880	1790	1120	1145	1010
	Montrose, Colo	1405	1340	1000	960	1910	1495	1630	1055	1265	1130	1000	1000	1395	1595	490	1065
	Grand Junction, Colo	1295	1220	840	910	1175	1495	1295	1310	1310	1340	1035	1265	1440	1065	760	([c])
	Huntington, Utah	1570	1505	1075	1120	1920	1945	1570	1955	1695	1450	1185	1090	1680	1295	840	1075

[a] Tests were made at Ames following a heavy rain to which the tile had been exposed.
[b] Exact breaking load not noted; approximately 1,200 pounds.
[c] Tile badly swollen and cracked. Not broken in machine.

TABLE 9

Results of Tests of Experimental Cement Drain Tile (1914)

[Average total breaking load in pounds.]

Exposure	Location	Tile series No.— 1	2	3	4	5	6	14	15	7	8	9	10	11	12	13	16	Average of all tile
Atmosphere...	Ames, Iowa.......	2972	2660	2172	2317	3077	2537	2325	1617	1272	945	1667	1430	1245	1095	1340	1212	1866
Fresh water...	Columbia, Mo.....	2687	2492	2585	2670	2347	2642	2447	1565	1177	1022	1617	1782	1200	1172	1472	1077	1871
	Crookston, Minn..	2670	2917	3000	2672	2385	2705	2765	1545	1465	997	1582	1813	1357	1037	1437	940	1955
Average.	....	2678	2704	2792	2671	2366	2673	2606	1555	1321	1009	1599	1797	1278	1104	1454	1008	1913
Individual maximum.	....	2760	3085	3230	2950	2590	2885	2780	1770	1515	1075	1705	1870	1440	1200	1485	1155	....
Individual minimum.	....	2580	2385	2480	2394	2140	2525	2340	1320	1145	950	1505	1695	1200	920	1405	880	....
Alkali water...	Garland, Wyo.....	3282	2957	2655	2715	2697	2125	2602	1485	1402	795	1505	1117	1265	650	1142	690	1818
	Fort Shaw, Mont..	2625	2530	2602	2087	2502	2630	2832	1532	1247	1047	1557	1532	1427	1012	1210	980	1834
	Sunnyside, Wash.	2552	3145	2275	2580	2537	2130	2497	1375	1110	985	1727	1695	1352	1035	1445	1002	1840
	Yuma, Ariz.......	2995	2990	2255	2437	2212	2125	2597	1632	1380	1072	1682	1810	1367	983	1192	1050	1861
	Roswell, N. Mex..	2717	3140	2665	2535	2850	2497	2737	1610	1322	1040	1555	1395	1435	1067	1455	1077	1943
	Montrose, Colo....	2797	3052	2280	3220	3150	2520	2805	1220	1372	980	1702	1342	1197	1000	1495	777	1931
	Grand Junction, Colo.	2680	2895	2130	2342	2085	2502	2720	1740	1257	875	1335	1302	1325	1150	1252	760	1769
	Huntington, Utah.	2270	3455	1677	3225	2707	1462	2837	1915	1537	1097	1932	1762	1572	1137	1487	957	1939
Average.	....	2734	3020	2317	2643	2593	2249	2703	1564	1328	986	1624	1494	1368	1004	1335	912	1868
Individual maximum.	....	3420	3590	3365	3500	3230	2985	3175	2105	1605	1185	1945	1980	1695	1265	1790	1145	....
Individual minimum.	....	2105	2490	1375	1825	1900	1440	2265	1220	900	770	1175	1055	1110	570	1000	490	....

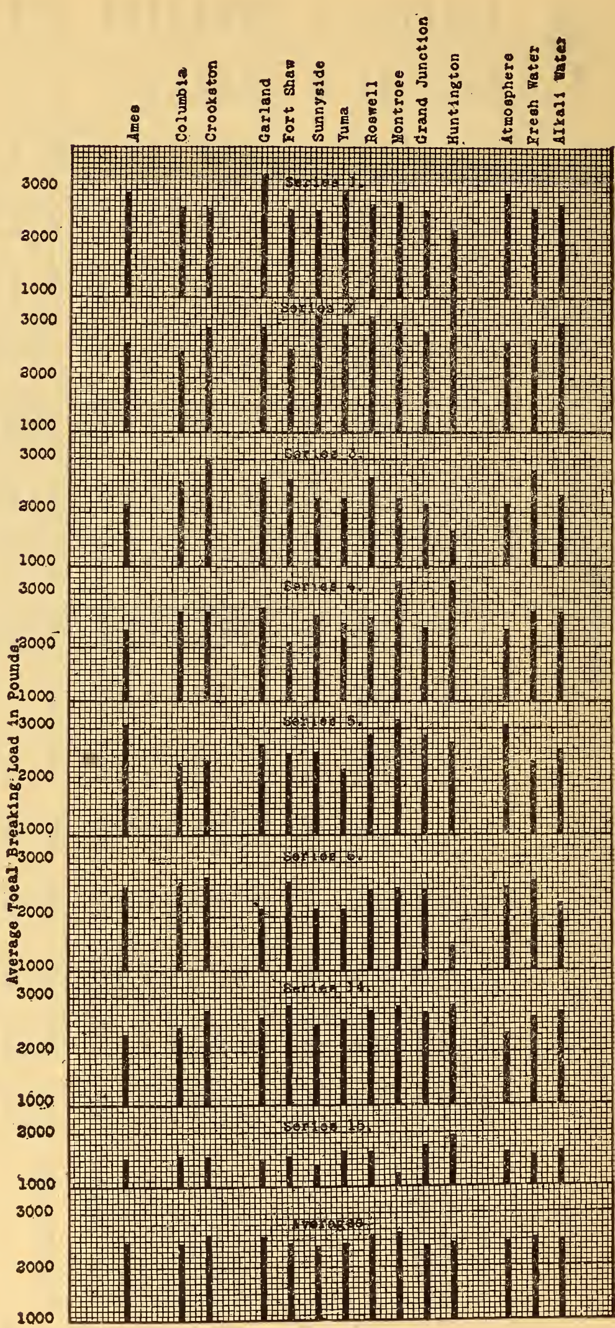

FIG. 48.—*Results of first year's tests of hand-made cement drain tile. (See Table 9 for detailed results)*

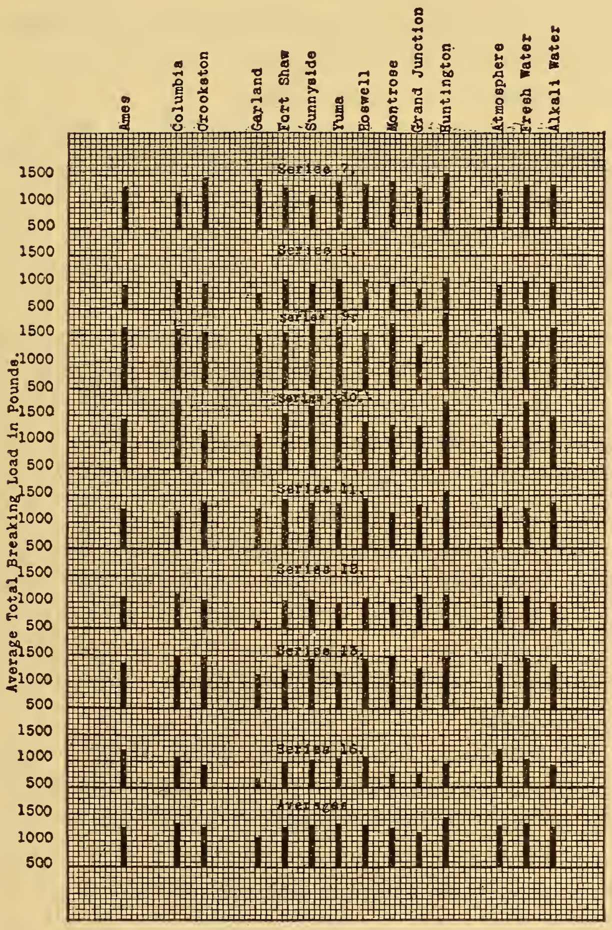

FIG. 49.—*Results of first year's tests of machine-made cement drain tile. (See Table 9 for detailed results)*

The variations in results of the same mixtures at the same or several points may also be due in part to the nonhomogeneity of the material, due in most part to nonuniform or insufficient "packing" in the machine, or "tamping" by hand. With the same materials the two factors which enter into the strength of the product are "richness" or proportion of cement and the fabrication or process of manufacture. A rich mixture alone will not insure a product of good quality. The low strength results obtained in a number of cases of the richer mixtures can be explained by poor tamping, especially in the handmade tile, in whose broken surfaces rings of untamped material were apparent. Even though extra care is taken in the tamping there is certain to be some variation in density which will affect the strength.

The great majority of the tile were unaffected in any manner at any of the projects. At Sunnyside, Wash.; Yuma, Ariz.; and Roswell, N. Mex., it may be stated that none of the tile showed any abnormality whatever. At Garland, Wyo., the leanest mixtures, series 8, 12, and 16, showed reductions in strength considerably below the averages for these series at all points. Series 10 was also below the average, but the results are explained by the fact that the tile were completely saturated, an unusual condition for the tile in this series, which may be due to excessive porosity. At Fort Shaw, Mont., one tile each of series 4 and 5 showed reduced strength, but the remaining two of the same series were about normal.

At Grand Junction, Colo., the tile made of the leanest mixture (series 16) were swollen and cracked, as shown in Fig 50. The tile made of sand-cement, series 15, while of normal strength showed a softening at the edges and several square inches of one of the tile was similarly affected although the breaking strength was normal.

At Huntington, Utah, the tile of series 6 appeared to be affected by the alkali. Although these tile withstood loads of over 1,400 pounds, there were a number of longitudinal and circumferential cracks apparent before testing and the fractured surfaces appeared white.

FIG. 50.—*Swollen and cracked tile of series 16 after one year's exposure at Grand Junction, Colo. The interior surface is cracked similar to the exterior*

At Montrose, Colo., the tile of series 15 appeared to have been affected by alkali. On one of the tile the concrete at one end was softened, apparently due to alkali, and both failed under comparatively small loads. The result obtained for tile 16a was abnormal, while that of 16b was rather above the average for this series. The early failure of the former may have been due to cracks which were overlocked at the time the tile was placed the year previous.

The absorption of moisture by the walls of the tile of the various series was noticeable at the different projects. The apparent amount of absorption varied with the amount of water present in the soils at the various points, and it was found that some of the series would be apparently saturated where the ground was barely moist while other series were apparently only slightly damp, even where the drain was filled with mud and water. Of the handmade tile and under the worst conditions series 2 was, with very few exceptions, found to be slightly damp, as indicated by the appearance of the fractured surfaces. This difference is not alone due to the variation in the proportions of the cement, since series 3, 4, 5, and 6, the richest mixtures used, were nearly always found partially or completely saturated. The term saturated is indefinite and inexact, since the condition was determined only by observation, but was used to indicate a dark spongy appearance of the fractured surface common to water-soaked concrete. The tile of series 14, next to those of series 2, showed the smallest amount of absorption, while the tar-coated tile of series 5 and the tile of series 6, containing the ferrous sulphate, were usually found to show the greatest absorption. We have no explanation to offer for the saturation of the tile of series 5 and 6.

The absorption of the machine-made tile varied as the amount of cement contained in them. The tile of series 9 and 10 were usually found apparently dry or only partially saturated with a few wet spots in the fractured surfaces while the tile of series 8, 12, and 16, the leanest mixtures, were always found saturated. Some low results obtained may be partially due to higher porosity, which caused the tile to be saturated when tested. This condition would also tend to increase the danger of failure due to alkali action at a later period.

VII. CONCLUSIONS

The details of this investigation and the results of the first year's tests are published at this time because of their economic value in demonstrating to those who are now using or considering using cement drain tile that special care should be observed to employ only the best materials and good workmanship in its fabrication, and if these precautions are not observed failure will result if the drain is located in some of the more concentrated alkali soils similar to those found at Grand Junction, Colo., and Garland, Wyo.

Drain tile manufactured in a manner as herein described for series 2, 9, 10, 11, 13, and 15 of cement mixtures not leaner than one part cement to three parts of aggregate are apparently unaffected structurally when exposed for one year in operating drains in very concentrated alkali soils, similar to anv of those included in this investigation.

Drain tile made from cement mixtures leaner than one part cement to three parts of aggregate should not be used in localities where the character of the alkali and concentration are similar to that found at the site of the experimental drains at Grand Junction, Colo., Montrose, Colo., and Garland, Wyo., and it is possible that subsequent results will show that no leaner mixture should be used in any district where appreciable alkali is found.

Drain tile manufactured in the manner herein described of one part cement to four parts of aggregate, the leanest mixture used, is apparently unaffected structurally by exposure for one year in an operating drain in localities where the character of the alkali and the concentration are similar to those found at Fort Shaw, Mont.; Sunnyside, Wash.; Yuma, Ariz.; and Roswell, N. Mex.

Other than the above, no very general conclusions should be drawn from this investigation until the results of further tests are obtained. It is anticipated that this report will be amended from time to time as the results are available.

The Bureau would be pleased to receive information concerning the behavior of concrete exposed to strongly alkaline soil which may come to the attention of engineers or others interested in the use of concrete under these conditions.

WASHINGTON, February 6, 1915.

[Continued from page 2 of cover.]

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